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Dissolved-Air Flotation Treatment of Combined Sewer Overflows

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DISSOLVED-AIR TREATMENT
OF
COMBINED SEWER OVERFLOWS

A DEMONSTRATION PROJECT OF A PROTOTYPE
TREATMENT PLANT DESIGNED TO TREAT WASTES
FOUND AT A COMBINED SEWER OVERFLOW

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
DEPARTMENT OF THE INTERIOR

by

RHODES TECHNOLOGY CORPORATION
HOUSTON, TEXAS

CONTRACT NUMBER 14-12-11

JANUARY 1970

FWPCA REVIEW NOTICE

This report has been reviewed by the Federal Water Pollution Control Administration and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Federal Water Pollution Control Administration. The use of commercial product names does not imply endorsement by the Federal Water Pollution Control Administration.

ABSTRACT

A dissolved-air flotation system was evaluated for primary treatment of combined sewer overflows. The major pieces of component equipment were a gyratory screen, hydrocyclones, an air dissolving tank, and a flotation cell.

The principal aspects investigated were: (1) Performance of the system during rain events and dry periods; (2) Evaluation of individual components; (3) Capital costs and operating costs for utilizing a flotation system for various size combined sewage overflows; (4) The adaptability of the system for automation and use in remote location; and (5) The ability of the system to treat intermittent and highly variable flows from combined sewage systems. Some chemical aids to flocculation were also tested.

The system performed comparably to conventional clarifiers. It appears dissolved-air flotation systems would be economical for handling combined sewer overflows up to 8 MGD. Automation of dissolved-air flotation systems appears possible with conventional control equipment. Chemical aids to flocculation appear to have promise that warrants further study.

The system was unique in that all liquid flow passed directly through the air dissolving tank with no recycle. Domestic sewage was studied in lieu of combined sewage during periods of no rain.

Conclusions, recommendations, and benefit-cost relationships are presented in the report. A description of the demonstration plant and of the drainage area served by the flotation system are appended.

This report was submitted in fulfillment of Contract 14-12-11 between the Federal Water Pollution Control Administration and Rhodes Technology Corporation, Houston, Texas.

CONTENTS

Section Page

Abstract

I - Results and Conclusions Recommendations 1

II - Introduction 5

III - Initiation of Investigation and Site Selection 13

IV - Characteristics of System Components 16

V - Air Flotation Studies and Treatment Plant Design 32

VI - Design Details of Major Component Parts 38

VII - Sampling and Initial Plant Modifications 43

VIII - Testing and Evaluation 53

IX - Additional Testing of Chemical Aids to Flocculation 67

X - Component Parts Performance 75

XI - Benefit-Cost Relationships 88

XII - Possibilities for Automation and Other Potential Applications 95

XIII - Acknowledgements 106

XIV - References and Bibliography 108

XV - Appendices

FIGURES

Figure		Page
1	Schematic Diagrams of Various Methods of Dissolving Air in Waste Water	22
2	Schematic Diagram of an Hydrocyclone	26
3	Drum and Traveling Screens	29
4	Circular Vibrating Screen	30
5	Air Dissolving Tank	33
6	Flow Diagram - Combined Sewer Effluent Treatment Plant	36
6a	Demonstration Pilot Plant	39
7	Pressure Control Valves	41
8	Flotation Tank	42
9	Sample Point Diagram - Demonstration Pilot Plant	44
10	Distribution Box at the Fort Smith "P" Street Pollution Control Facility	48
11	Modification of Distribution Box at Fort Smith "P" Street Pollution Control Facility	49
12	Detail of Flotation Cell Showing the Baffle Plate Installed to Trap Large Air Bubbles	50
13	Inlet Header as Built; Suggested Design for Inlet Header	51
14	Relationship Between Suspended Solids Removal Efficiency and Pressure Differential	81
15	Location and Size of Holes Cut in Exit Weir of One Cell of Flotation Tank	86
16	Benefit-Cost Ratios	92
17	Automated Standby Combined Stormwater - Domestic Sewage Treatment Plant	97

TABLES

Table		Page
1	Air Dissolving Tank, Air Flotation Tank	24
2	Percent Removal of Sewage Components When Different Equipment Combinations Were Used (No Chemical Flocculants)	55
3	Percent Removal of the Various Components When Different Chemical Treatments Were Used. All Mechanical Separatory Equipment Was On Stream	59
4	Percent Removals of the Various Components During Rain Events. All Mechanical Separatory Equipment Was On Stream	62
5	Summary of Removal Rates	64
6	Comparison of Sewage Strengths	65
7	Additional Chemical Tests	68
8	Additional Chemical Tests	69
9	Additional Chemical Tests	70
10	Chemical Treatment Costs	72
11	Oil Removal Test	73
12	Supplementary Data On Pressure Drop Across Cyclones	78
13	Effect of Air Feed Rate and Pressure Differential On Total Suspended Solids Removal, Percent	80
14	Effect of Flow Rate On Suspended Solids Removal	86
15	Effective Flotation Depth	87
16	Costs and Benefits, Air Flotation and Conventional Clarifiers	89
17	Physical Sizes and Land Areas Required by Conventional Clarifiers and Dissolved Air Flotation Units	93

SECTION 1

RESULTS AND CONCLUSIONS

RECOMMENDATIONS

RESULTS AND CONCLUSIONS

1) The dissolved-air flotation system removed suspended solids from combined sewage with 12 minutes retention time as effectively as conventional clarifiers with 4 hours retention time. During rain events and without chemical aids, the system removed an average of 69 percent of the suspended solids passing a gyratory screen installed to removed gross particles. Injection of alum and a polyelectrolyte into the system increased the removal rate to an average of 84 percent. Alum alone was ineffective. Without chemical aids, BOD reduction averaged 26 percent. When chemical flocculating aids were injected, BOD reduction increased to an average of 42 percent.

2) Efficiency during dry weather was essentially the same as during rain periods.

3) Automation of dissolved-air flotation systems appears feasible for the treatment of intermittent, variable, and high instantaneous flow rates normally encountered with combined sewage overflow. Surge tanks or retention basins are unnecessary when dissolved-air flotation is used as a treatment for combined sewer overflows, provided there are approximately 2 minutes storage time available in the sewer system.

4) Total annual costs for dissolved-air flotation systems are less than costs for conventional clarifiers for flows up to 8 million gallons per day. For treatment of storm water flows more than 8 million gallons per day, conventional clarifiers show lower total annual costs. As capacities increase, operation and maintenance costs become very significant in the dissolved air process. However, dissolved-air flotation units require only one-tenth as much land area as conventional clarifiers.

5) The foam collected contained 5 to 7 percent dried solids of 70 percent volatility. Conventional sludge handling techniques may be used to dispose of the foam, except sludge thickeners can probably be eliminated.

6) Evaluations of individual components show the gyratory screen, the full flow air dissolving tank and the flotation cell were very effective. Cover against wind and rain was essential to full efficiency of the flotation cell. The hydrocyclones used could not be evaluated fully because of periodic plugging. However, the cyclones did remove the kind of dense inorganic materials which overload sludge digesters or form clinkers during sludge incineration.

RECOMMENDATIONS

1) Dissolved-air flotation of combined sewer overflows should be considered as an alternate to conventional treatment methods.

2) Additional research is necessary to fully evaluate hydrocyclones. The solids collection pots and pneumatically operated dump valves should be eliminated from the cyclones and replaced by adjustable apex valves allowing continuous cyclone underflow.

3) Consideration should be given the use of screw conveyors to move foam from the foam collection troughs. This will permit a drier foam to be produced.

4) Alternate screening mechanisms should be considered. In future applications of the present dissolved-air flotation design, a comprehensive study should be made of the characteristics of suspended solids for each application.

5) Pilot plant studies of chemical aids to flocculation are recommended to determine costs of producing waters of secondary treatment plant quality.

6) The efficiency of a total treatment unit consisting of the dissolved-air flotation system for both primary and final clarification of trickling filter and activated sludge effluents and combinations of the following secondary and tertiary treating systems should be investigated:

a. Rapid sand filtration.

b. High rate trickling filters.

c. Activated carbon filtration.

d. Chlorination or hypochlorination.

7) Additional research and pilot plant work is recommended to study the applicability of dissolved-air flotation to the treatment of various industrial wastes.

SECTION II

INTRODUCTION

THE COMBINED SANITARY AND STORM SEWER OVERFLOW PROBLEM IN THE UNITED STATES

PROPOSED SOLUTIONS TO THE OVERFLOW PROBLEM

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INTRODUCTION

THE COMBINED SANITARY AND STORM SEWER OVERFLOW PROBLEM IN THE UNITED STATES

The flooding of basements, low lying buildings, and land by combined sewage causes immeasurable direct damage and inconvenience to an estimated 36 million people in over 1300 cities and communities in the United States. Collector sewers which are too small for the large flows from storm water run-off are the major cause of the direct damage. The costs of this direct damage are spread indirectly in the form of higher costs for goods and services to the entire U. S. population (1).

Reduced water quality is one example of indirect damage caused by storm water run-off and combined sewer overflows. Many treatment plants have insufficient capacity to remove the silt and organic matter flushed from sewers by the surge of storm waters. It is not uncommon, after an extended dry spell, for treatment plant operating personnel to bypass the first waters received after the start of a rainfall to avoid a buildup of grit and silt in the clarifiers. Receiving waters also suffer quality reduction when improperly maintained or inoperative flow regulators permit storm waters to overflow directly to receiving waters, bypassing all treatment facilities.

Because of these and many similar situations, there is great need for low-cost and reliable facilities to handle combined sewage overflows.

The concept of the combined sanitary and storm system is several thousand years old (2). Originally, sewers were used for storm drainage only. Domestic wastes were the responsibility of the individual householder and were disposed of in dry wells, cesspools, and septic tanks. It became necessary to dump domestic wastes into the streets to be washed into storm drains when rains occurred. The practice spread. With increasing urban populations and the advent of industrialization, true combined sewer systems became a fact through the piecemeal addition of open channels draining into the storm sewers. Eventually, closed conduits and pipes were added to the system. In many instances the old closed facilities still exist and are in service, but, because they were designed for small drainage areas and have a limited capacity, they are overburdened even in dry weather. During storm periods the combined waste waters cause local flooding.

Each of these old sewers has its own outfall at a nearby river or stream. The result is a multitude of outfalls and evil-smelling areas along water courses. Interceptors have been constructed to alleviate the situation, but overflows still course through the outfalls. More than 400 such outlets are still to be found in Cleveland, for example (3).

The total number of cities having combined sewers has decreased in recent years. The reduction has been accomplished by building new interceptors to separate the wastes and by rebuilding the old sewer systems. Most new construction involves separate sewers, but occasionally the separate sewers in new suburbs and residential areas are connected to the interceptors of a combined system in older sections of the communities, compounding the existing overflow problems. Some combined facilities are still being constructed in cities which already have combined sewers (4).

Haphazard additions to sewer systems have led to numerous overflow and treatment problems. Additionally, lax enforcement of sewer regulations and restrictions plus ambiguous and conflicting interjurisdictional construction codes have led to large networks of sewer lines feeding to central treatment facilities. For example, Cleveland, Ohio, serves 32 governmental units outside its city limits; many of these are without any form of municipal organization (1).

These problems have not gone unrecognized, and in some areas sanitary districts or authorities with broad powers and adequate financial structure have been established to help combat and correct these problems.

The American Public Works Association in its report for the FWPCA, "Problems of Combined Sewer Facilities and Overflows" (1), states that over 50 percent of the jurisdictions interviewed have problems due to infiltration of ground waters. The surcharge of sewers due to infiltration of ground waters is a problem common to both combined and separate sewer systems. The separate sewer systems found in much of the Southwestern United States are particularly susceptible to infiltration of ground waters during both wet and dry weather.

Dry weather infiltration occurs when sewers are below the water table. Infiltration during dry weather is often unrecognized until attempts are made to relate water utility service pumping output to waste water treatment plant flow records. Dry weather infiltration waters together with the existing flow of sanitary wastes often approach the capacity of the treatment facilities, leaving little or no capacity for rain waters. The infiltration of ground water into the sewer systems during rain events causes many of the same problems as occur in combined sewers: Namely, flooding of basements, overloading of treatment facilities, and discharging of wastes through overflows.

The magnitude of the infiltration problem is illustrated by an unsigned article in "American City" (5). The author discusses the methods used by the city of North Miami, Florida, to dispose of daily treatment plant effluents containing up to 75 tons of salt from salt water constantly infiltrating the municipal sewer system.

Among the methods used to control infiltration are better supervision of the installation of the facilities and the sealing of existing facilities against infiltration.

PROPOSED SOLUTIONS
TO THE OVERFLOW PROBLEM

The cost of separating the combined sewers in the United States has been estimated up to $30 billion plus an additional $18 billion for plumbing service connections to private property (1). Other sources list the cost at $10 million per square mile or about $1,000 per family served (3). The cost in time and inconvenience to the populations involved is beyond estimation; the need to alter roof and basement drains alone would entail a tremendous public relations effort and would provide fertile ground for countless property damage suits. Peters and Troemper (6) report on the difficulties encountered by the Springfield, Illinois, Sanitary District in removing or attempting to remove the rainwater downspouts from residences. Several questionnaires, letters, and inspections were necessary to approach 100 percent compliance with a long-existing regulation concerning the connection of downspouts to sanitary sewers. The authors report that compliance with the regulation eliminated flooding of basements due to surcharge of sanitary sewers during rainstorms.

Many alternatives to complete separation are available. Although each situation presents its own problems, there are enough similarities that solutions can be categorized. The Chief of the Storm and Combined Sewer Pollution Control Branch, Federal Water Pollution Control Administration of the U. S. Department of Interior, in a speech presented at the Spring 1968 Meeting of the New England Water Pollution Control Association, discussed three basic approaches that can be utilized to solve combined sewage or storm water pollution problems:

1) Control.
2) Treatment.
3) Combinations of control and treatment.

It is not the purpose or intent of this report to treat or discuss all the details and ramifications of each categorical solution or even to list all the possible solutions. Some of the more publicized solutions are listed for illustrative purposes.

The storage of storm induced overflows in limestone tunnels deep under Chicago has been mentioned; the sale of excavated limestone would help to defray some of the construction costs (7).

Two large collapsible rubberized storage tanks, each of 100,000 gallons capacity, to be anchored in the Anacostia River to store overflows during heavy rainfalls are being constructed and installed in Washington, D. C. This is not intended to provide complete relief to the overflow problem; need for ten tanks is estimated. After the storm ends, stored waste waters will be pumped to currently available treatment facilities. Similar projects are in process at Cambridge, Maryland, and Sandusky, Ohio.

Chemical additives for waste water have been developed which reportedly increase the flow in sewer pipes up to 2-1/2 times, thereby achieving peak-flow relief without new construction (8). A novel plastic sealant to eliminate excessive sewer flows due to infiltration of ground waters has been reported by the same source.

Chlorination and hypochlorination of storm waters are being investigated by the city of New Orleans. Although the sewers in New Orleans are separated, storm waters pumped into Lake Pontchartrain carry a tremendous load, necessitating the closing of some public beaches after major rainfalls. The City of Boston is studying the use of retention basins for storage and sedimentation in conjunction with hypochlorination for the treatment of storm overflows from its combined sewer system.

Some treatment or control methods have been in use for some time in various communities throughout the United States and abroad.

One current test, supported by FWPCA, has been described as follows.

"One of the Dallas grants in the amount of $828,750, or 75 percent of the total eligible project costs, funds a project which consists of the design, construction, and evaluation of a facility to treat overflows from sewers carrying a mixture of domestic waste water plus storm water infiltration. Physical features include a diversion structure, a pumping station, flocculation and sedimentation basins, chemical feed facilities, and a conveyance system for transporting waste lime sludge from a municipal water plant to the storm water treatment facility. Unique features of this project include the demonstration of tube-type clarifiers and the evaluation of the utilization of waste chemicals from a water-softening plant to enhance settling in the waste water sedimentation unit" (9).

SECTION III

INITIATION OF INVESTIGATION AND SITE SELECTION

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INITIATION OF INVESTIGATION AND SITE SELECTION

In mid-1966, the Federal Water Pollution Control Administration advertised in The Commerce Business Daily for concepts and new approaches to the solution of the problems of combined sewer facilities. Engineers of Rhodes Technology Corporation, Houston, Texas, were convinced that the problems involved in the treatment of sanitary and combined sewage were not extremely different from the problems involved in the treatment of waste water in oil fields and that the techniques that had been used to clarify waste water in the oil fields would be directly applicable to the treatment of sewage. Considerable experience has been gained over the past 15 to 20 years in the use and operation of dissolved-air flotation units to remove oil and suspended solids from oil field waste water. Additionally, considerable experience has been gained in the use of hydraulic cyclones or hydrocyclones for the removal of heavy materials such as silt, sand, and clay from water.

A proposal was submitted to FWPCA suggesting the linking of these pieces of equipment into a single treatment unit of extremely short retention time (about 10 minutes).

The Federal Water Pollution Control Administration awarded the contract for this study to investigate the concept of using hydrocyclones, a dissolved-air flotation unit, a low liquid retention time, and screens as well. Screens were thought necessary so that particle size entering cyclones could be limited. Comminutors were not included because sludge digestion was not a part of this study.

Included in the contract was a provision calling for the selection of a site for the dissolved-air flotation unit. Items to be considered in the site selection included the availability of the following items:

1) Land for the erection of the dissolved-air flotation plant.
2) Storm waters during storm events.
3) Domestic waste to be used in lieu of storm water in dry weather periods.
4) Fresh water for the dilution of domestic wastes, should the need arise.
5) Electric power.
6) A laboratory for the analysis of the influent and effluent waste streams.
7) The cooperation of the necessary municipal officials and employees.

Several of the sites inspected included Kansas City and St. Louis, Missouri; Oklahoma City, Norman, and Stillwater, Oklahoma; and Fort Smith, Arkansas. Each of the sites offered many possibilities for the successful completion of the project.

Fort Smith, Arkansas, was selected because it was the only site at which all of the desired items were available.

This report covers results of bench scale tests, design of a dissolved-air flotation plant, and operation of the plant from October 1967 to December 1968.

SECTION IV

CHARACTERISTICS OF SYSTEM COMPONENTS

[redacted]

CHARACTERISTICS OF SYSTEM COMPONENTS

Dissolved-Air Flotation

Air flotation systems have been used for many years in the mining industry to concentrate low grade ores by frothing. Hanson and Gotaas (10) claim the first froth process was patented in 1860 by Hanes. The froth process does not use dissolved air; air is injected by several means. In recent years the trend has apparently been to use air injected through the shaft of an impeller. The impeller breaks the air stream into millions of bubbles creating a froth or foam which rises to the surface, floating the ore or gangue, whichever is lighter. In most cases frothing is aided by the use of chemicals such as alcohols, resins, or soaps.

The flotation method of separating ores from overburden material is discussed in much research literature. Gaudin (11) mentions that gas flotation was first recognized as early as 1901. Fromet obtained a British patent on the use of gas bubbles to remove sulphite minerals from ores in 1903. The vacuum process is mentioned by one author as being patented in 1907. Norris (12) was issued a patent in 1907 in which a pressurized slurry of water and ore was used. Elmore (13) was granted an English patent in 1905 for the vacuum separation of ores. Previous systems, according to Elmore, used frothing aids such as oil, tars, and soaps.

Elmore claimed his system would reduce the amount of chemical aids needed. Another English patent was awarded for the use of a pressurized flotation system in 1906 to Suhman, Kirkpatrick-Picard, and Ballot. The patent was also granted in the United States (14).

All dissolved air systems involve injection of air into a liquid under pressure followed by transfer of the liquid to a cell where the air leaves solution in the form of small bubbles.

D'Arcy (15) claims the modern dissolved-air flotation system was invented in Norway by Sveen and Pederson. No date for the invention is given. The Sveen-Pederson process is widely used in the paper and pulp industry for the clarification of "white water". The dissolved-air flotation system is widely used in industry, as indicated by many references throughout the literature to its various applications. Specific applications include the removal of oil and suspended matter from oil field wastes. The use of dissolved-air flotation systems is discussed in several papers relating to the separation of oils and fats in the soap and detergent industry. Dissolved-air flotation systems are also used by the food processing, meat packing, and slaughterhouse industries. Several steel mills report the use of dissolved-air flotation for the removal of grease and oil from water, while both the Santa Fe and the Union Pacific railroads report the use of dissolved-air flotation to clean wash water. Chrysler Corporation reports using the dissolved-air flotation system to clean process water (16).

The operator of a 400-gallon-per-minute dissolved-air flotation system installed at the Indiana Farm Bureau Cooperative Association Refinery near Mount Vernon, Indiana, claims a BOD reduction of 78 percent and a suspended solids reduction of 93 percent when waste waters with pH 9 are fed through the system. In addition, he reports a 90 percent removal of oil (17).

An extensive literature search reveals a considerable amount of data relating to the design and use of flotation cells. Howe (18), in a mathematical derivation of flotation cell design, recommends that considerable experimentation with each different waste precede the use of his equations in determining the exact criteria for flotation cells. He further states that particle size and density, liquid viscosity, and liquid density are factors to be considered in designing tank depth, overflow rate, and retention time. He goes on to state that bubbles released in the liquid are less than 130 microns in diameter, smaller than the bubble size in the froth system.

A comprehensive discussion by D'Arcy (15) of the use of dissolved-air flotation systems to separate oil from waste waters includes six important general considerations:

1) Dissolving a maximum amount of air in the influent.
2) Elimination of all entrained air as the release of

entrained air in the flotation system introduces turbulence and short circuiting.

3) Proper hydrodynamic design of the entire flotation system, especially the flotation chamber.
4) Selection of proper coagulant and floc-forming chemicals if they are required--always bearing in mind that the most economical as well as the most efficient chemicals should be used.
5) Continuous mechanical removal of oil or floc on the surface of the water in the flotation chamber.
6) Design of the entire system to produce a unit which will operate automatically under a wide range of conditions and which requres the minimum amount of trained personnel for its operation.

The equipment discussed by D'Arcy is operated by regular oil field personnel and seldom requires more than 3 man-hours per day, this time being used for mixing chemicals and lubrication of equipment. Chemical costs are in the neighborhood of \$2 per thousand barrels (\$48/million gallons) of waste treated and have been as low as 80 cents per thousand barrels (\$19/million gallons) when alum or activated silica are used for treatment.

The fundamental principles of dissolved-air flotation as applied to industrial wastes were discussed by Vrablic at the Fourteenth Annual Industrial Waste Conference at Purdue University (19). Among other things, Vrablic hints that advantage should taken of fact that oxygen is twice as soluble in water as nitrogen. He further claims that the flotation system makes use of three fundamental processes:

1) Adsorption of air bubbles on the solids.
2) Trapping of air bubbles by the solids.
3) Adhesion of air bubbles on the solids.

Vrablic states that hydrophobic solids will float much more easily than will hydrophillic ones. He recommends an air to solids ratio of 0.06 (lb of air/lb of dry solids).

Eckenfelder, et al, found a ratio of 0.02 most favorable (20). These researchers report the use of a laboratory scale model to treat domestic sewage. The scale model consisted of a stell pressure tank which was filled with waste activiated sludge, pressurized, and then shaken. The liquid was then released into a Lucite cylinder for decompression and foaming; periods of foam formation took up to 20 minutes. They report excellent suspended solids removal and further indicate that turbulence must be controlled to reduce the shearing of fine floc.

Results varying from between 20 and 82 percent removal of unemulsified oil are discussed by Rohlich (21). A 75 gallon-per-minute flow of waste water was directed through an air flotation unit using a retention time of 12 minutes. The tank had a surface area of 34 square feet and was 3-1/2 feet deep.

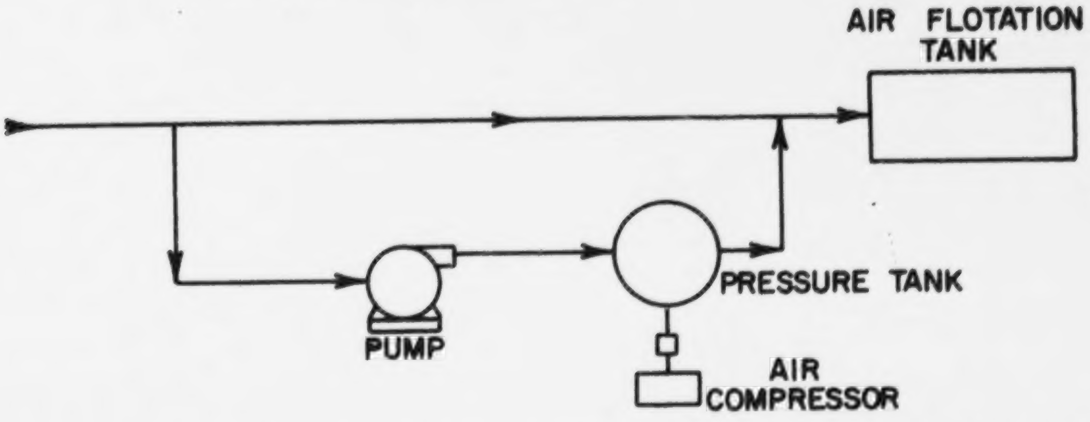
The air dissolving tank had a capacity of 150 gallons with a resulting retention time of 2 minutes.

Rohlich feels that a retention time of 2 minutes is necessary to insure saturation of air in the liquid stream. Air was dissolved in the waste stream at a pressure of 50 to 60 pounds per square inch. The three types of pressurization shown in Figure 1 were attempted. These include the diversion of part of the influent stream through the pressure tank, recirculation and pressurization of the recycled waste water, and total pressurization with air injected through a venturi device. The experiments relating to total pressurization used a flow rate of 50 gallons per minute.

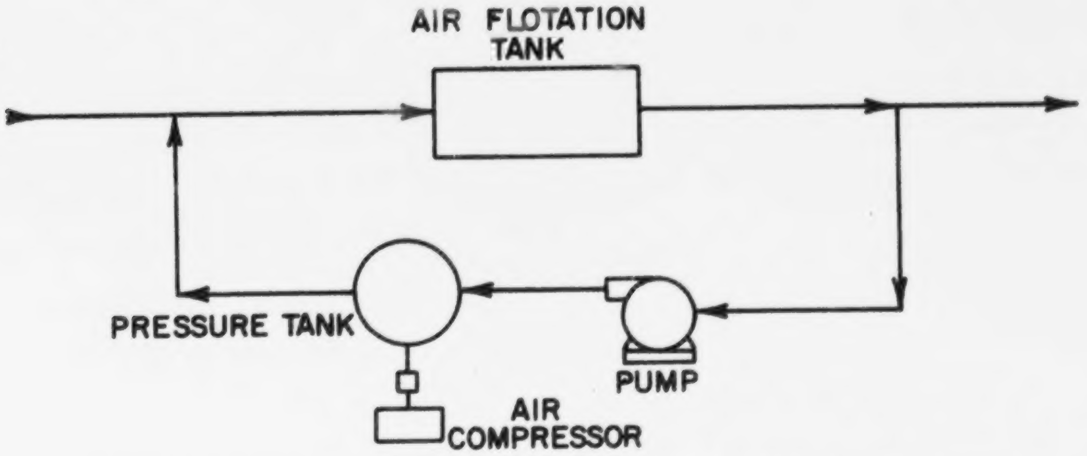
Prather (22) discusses the reduction in chemical oxygen demand (COD) in an oil refinery waste using dissolved-air flotation. In the waste discussed, the COD was due primarily to suspended solids. The dissolved-air flotation system in this application was originally designed to remove oil and suspended material. In order to achieve a significant removal of COD and suspended solids, pH adjustments were necessary. Values of pH between 8 and 9 are reported.

Hopper and McGowan (23) report the use of frothing to purify surface waters in a 1950 experiment using 34 different surface waters as test media. Nontoxic quaternary ammonium compounds were used in an attempt to reduce the bacterial content of drinking water. Bacterial reductions up to

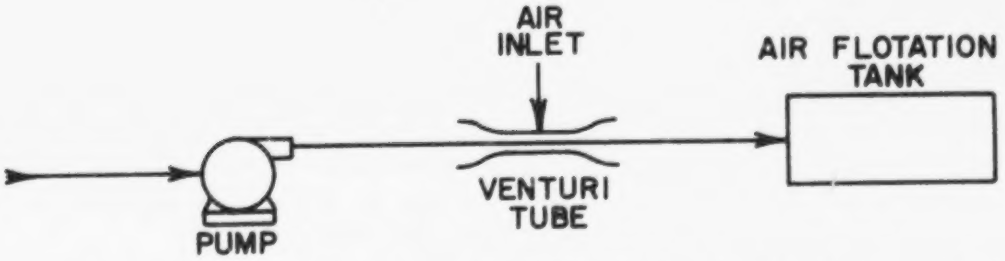
SCHEMATIC DIAGRAMS OF VARIOUS METHODS OF DISSOLVING AIR IN WASTE WATER


AIR FLOTATION TANK
PRESSURE TANK
PUMP
AIR COMPRESSOR

(a) DIVERSION OF PART OF FLOW THROUGH PRESSURE TANK


AIR FLOTATION TANK
PRESSURE TANK
PUMP
AIR COMPRESSOR

(b) DISSOLVING AIR IN RECYCLED WASTE WATER


AIR INLET
AIR FLOTATION TANK
VENTURI TUBE
PUMP

(c) INJECTION OF AIR THROUGH A VENTURI DEVICE

FIGURE 1

99 percent (plate count method) were reported, and 95 percent of suspended solids were removed. Cost of operating the system is reported as 5 cents per thousand gallons.

Air bubbles less than 100 microns in diameter were used for sludge thickening and total solids removal in several units reported by Katz and Geinapolos (24). The units being studied used a 50 percent recycle rate in which air was introduced at the rate of 1 cubic foot of air per 100 gallons of recycle water. The authors indicate dry solids loading rates of 10 to 20 pounds per square foot per day for activated sludge and 55 pounds per square foot per day for primary wastes. The units varied from 7 to 12 feet in depth. Katz suggests that the flotation system includes several types of flotation and that hindered flotation was one of the phynomena encountered. Sludge was thickened to a consistency of 3 to 4 percent solids.

Bubbles forming in sanitary sewage have terminal velocities of 0.14 inches per second. This value is the basis of a design discussed by Masterson and Pratt (25). They suggest that free air evolves in the air dissolving tank when over 60 percent of saturation is reached. However, they also state, "The greater the amount of air dissolved, the greater will be the (flotation) effect".

A summary of the pertinent suggested values reported in the design of dissolved-air flotation systems are given in Table 1 below:

TABLE 1

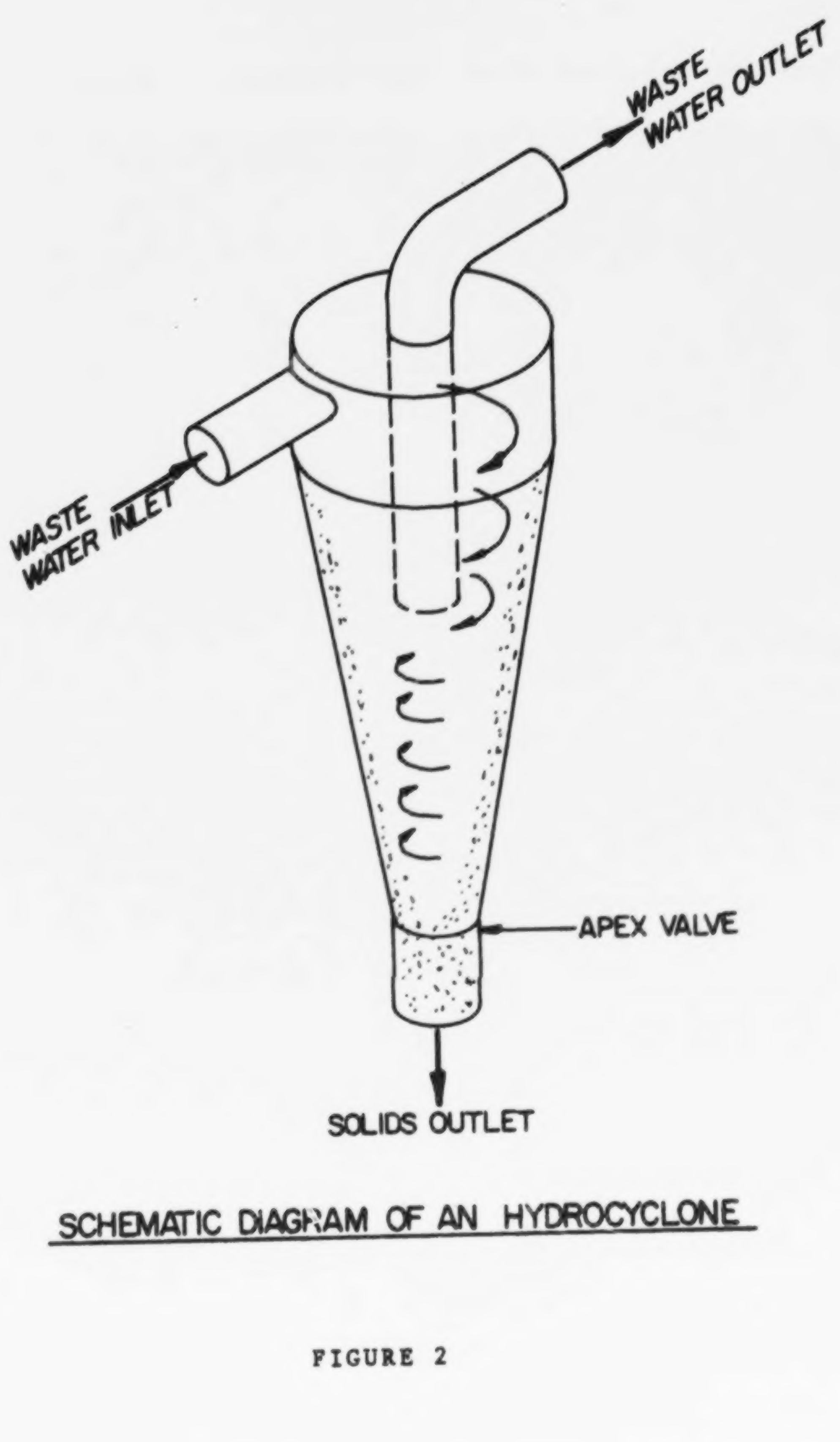
Air Dissolving Tank:	
Pressure -	50 to 60 psig
Retention time -	2 minutes
Air feed rate -	1 cu ft/100 gal waste
Recycle rate -	50 percent
Air to dry solids ratio -	0.02 to 0.06 lb air/lb solids
Air Flotation Tank:	
Dry solids loading rate -	55 lb/sq ft/day
Surface loading rate -	2.0 to 2.5 gal/sq ft/min
Depth -	3.5 to 12 ft

Hydraulic Cyclones

Storm water overflows and combined sewer systems receive a variety of dense materials; it is almost impossible to control the influx and arrival of these materials at treatment plants. In order to minimize the accumulation of the resulting sediments on the bottom of flotation tanks, Rhodes Corporation engineers, on the basis of their oil field experience, suggested the use of hydrocyclones for the removal of the dense material.

The pneumatic cyclone has long been used in the lumber and furniture industries for removing wood chips and sawdust from air streams. The hydraulic cyclone, or hydrocyclone, uses the same principle as the pneumatic cyclone. A comment by Pryor indicates that hydrocyclones were first used in the petroleum industry in 1939. Figure 2 indicates the general configuration of a cyclone in which an inverted cone has a cylinder attached to its wide end. Waste water is injected tangentially into the cylinder and is forced to travel in a spiral pattern through a shorter and shorter radius toward the narrow end. Centrifugal force causes the heavier particles to move to the outer edge of the stream. Upon approaching the narrow end of the cone, waste water escapes through a tube called a vortex finder running up the center of the cone. Solid materials which have been forced to the outside of the waste stream fall to the bottom of the cone, are collected, and disposed of.

Leniger states, "When dealing with suspensions of very fine particles, an obvious measure to be adopted consists of accelerating sedimentation by centrifugal force. There has been a choice between hydrocyclones in which a rotation of the suspension is produced by introducing it tangentially into a stationary apparatus and centrifuges (here termed clarifiers), in which the liquid is caused to rotate by revolving a drum. For hydraulic classification a so-called


WASTE WATER OUTLET
WASTE WATER INLET
APEX VALVE
SOLIDS OUTLET

SCHEMATIC DIAGRAM OF AN HYDROCYCLONE

FIGURE 2

hydrocyclone is not used with much success. Hydrocyclones have the advantage of simplicity and flexibility so that the results may be modified by altering various operating conditions. As opposed to other types of apparatus, they are better for classifying than for clarifying. The reason is that the high shearing stresses in the hydrocyclone promote the suspension of particles and oppose flocculation. A disadvantage lies in the fact that both the fine and coarse fractions are obtained in suspensions of relatively high dilution. Furthermore they only operate well in a medium of low viscosity" (27).

There is abundant literature on the theory and design of hydrocyclones. Broer (28) discusses efficiency as judged by the separating capacity and power consumption of the hydrocyclone, and Van der Kolk (29) investigates the ability of cyclones in series arrangements to protect expensive devices and to collect several grades of bulk material. Van der Kolk illustrates his discussion with several diagrams showing different schemes for connecting cyclones in series. He concludes his article with a discussion of the advantages of the various ways of linking the cyclones.

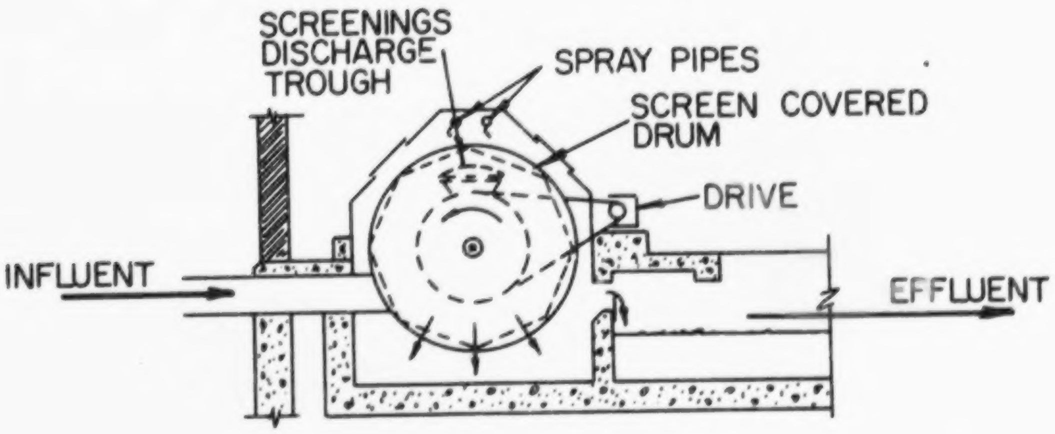
A major manufacturer (30) of hydrocyclones uses an advertising brochure for a very enlightening discussion on the use of hydrocyclones as classifiers. Among other comments, the manufacturer lists four major cyclone applications.

1) Classification or sizing of particles. Cyclones separate particles according to their relative mass rather than strictly by particle size. However, the generally accepted range of cyclone operation is from 35 mesh to 5 microns.
2) Degritting water or water suspensions of fine solids.
3) Desliming operations.
4) Closed circuit grinding classification.

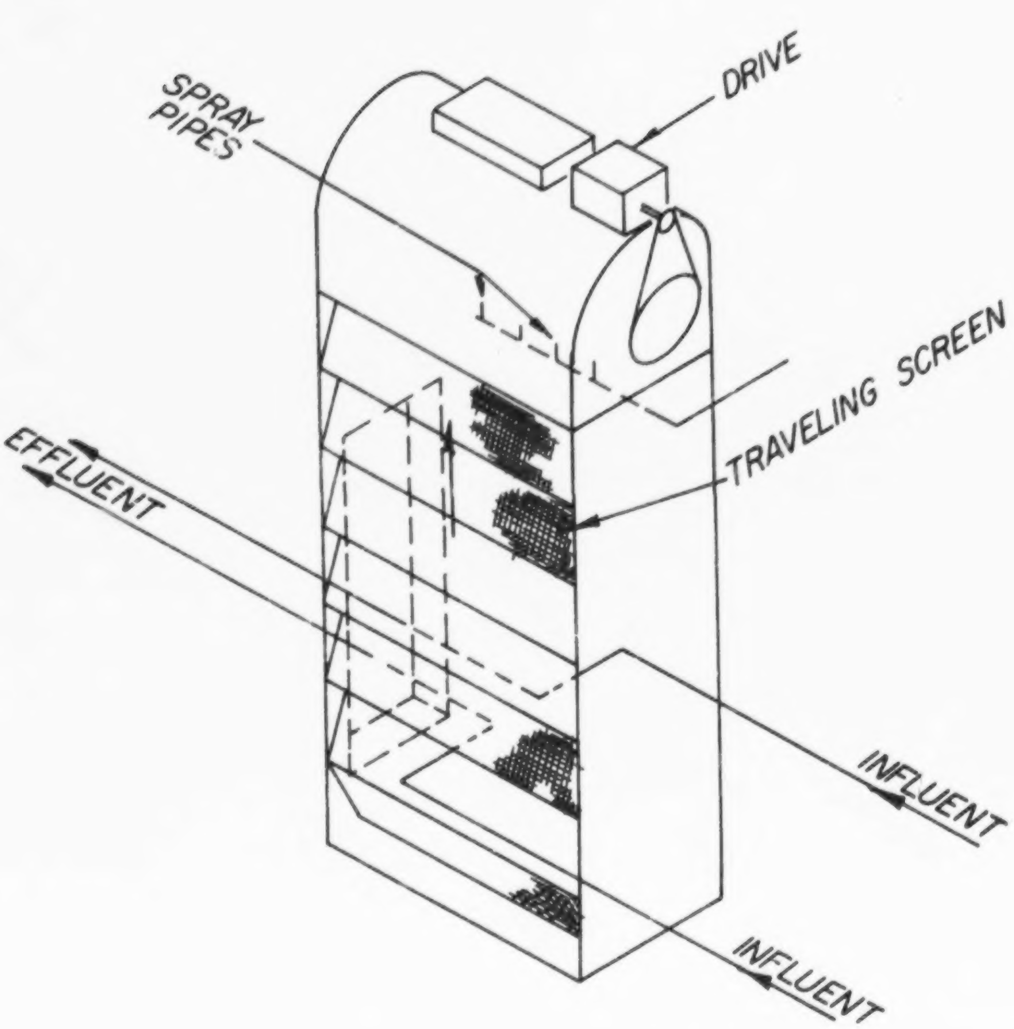
Screens

The apex valve of the hydrocyclone is generally of much smaller diameter than the inlet, and large particles which enter the cyclone can sometimes clog the apex valve. To prevent this plugging, the manufacturer suggested screening the waste water entering the cyclone. Of particular hazard are materials such as sticks, pencils, etc., which can bridge the narrow apex valve. Once bridged, the valve easily becomes further clogged with other materials and, within a short time, the cyclone must be removed from the system, dismantled, and unplugged.

The commonly-used bar screen is of no value in this application; turbulence can cause sticks to twist in such a way as to pass through the screen. Screens which are available for the operation envisioned include drum screens and endless belts illustrated in Figures 3a and 3b and vibrating screens illustrated in Figure 4. The vibrating screen apparatus

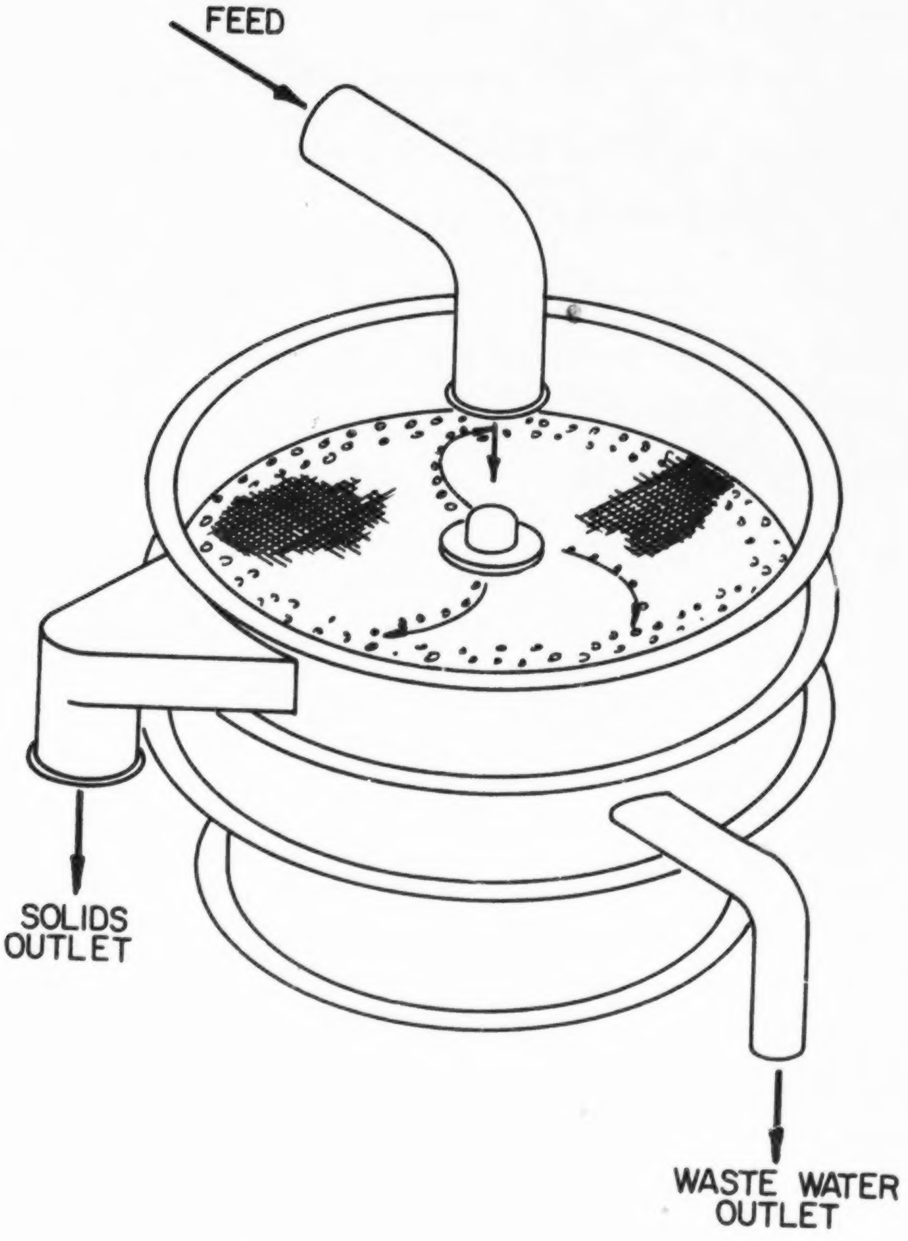

SCREENINGS
DISCHARGE
TROUGH
SPRAY PIPES
SCREEN COVERED
DRUM
DRIVE
INFLUENT
EFFLUENT

(a) DRUM SCREEN


SPRAY
PIPES
DRIVE
TRAVELING SCREEN
EFFLUENT
INFLUENT
INFLUENT

(b) TRAVELING SCREEN

FIGURE 3


FEED
SOLIDS OUTLET
WASTE WATER OUTLET

CIRCULAR VIBRATING SCREEN

FIGURE 4

has several advantages:

1) The screen is easily removed from the apparatus for replacement and changing of mesh size.
2) There is only one moving part.
3) The screen is self cleaning.

The vibratory screen is found in a variety of applications, including the removal of stones, rocks, and coarse material in mining operations; the removal of feathers in turkey and chicken processing plants; the removal of water from vegetables in the frozen food industry; and the removal of wastes in the vegetable and fruit canning industries.

SECTION V

AIR FLOTATION STUDIES AND TREATMENT PLANT DESIGN

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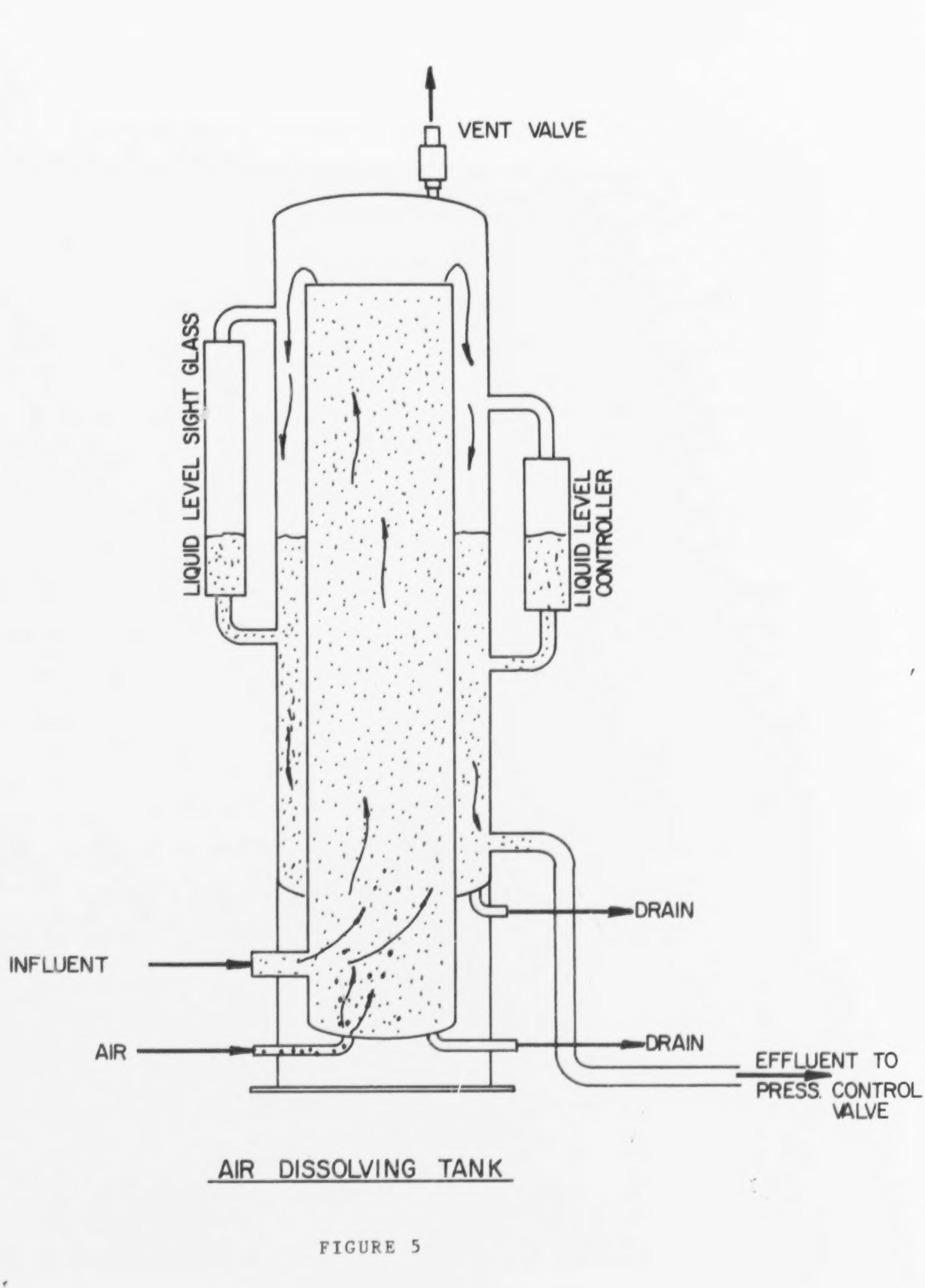
AIR FLOTATION STUDIES AND TREATMENT PLANT DESIGN

Items to be investigated before the dissolved-air flotation system could be designed included methods of dissolving air in the waste stream and design of the air flotation tank.

Several methods are often used for dissolving a gas in a liquid. Many of the conventional methods suggested in The Chemical Engineers' Handbook (31) were discarded because of the possibility of trapping suspended particles in the dissolving unit. Two designs were selected for trial. One design included the use of Raschig rings as a packing material. The other design is illustrated in Figure 5 and consists of a cylindrical outer tank with a stand pipe in the center of the tank. Air and the incoming waste stream enter the bottom of the inner stand pipe; air dissovles in the waste liquid as the air and waste liquid rise through the stand pipe. Additional air is dissolved as the waste liquid overflows the stand pipe and falls through the air gap at the top of the outer cylinder. Because oxygen is more soluble than nitrogen, the unit was designed for a constant flow of air through the air dissolving tank. Air deficient in oxygen but rich with nitrogen was constantly being replaced with oxygen-rich air for better dissolving efficiency.


VENT VALVE
LIQUID LEVEL SIGHT GLASS
LIQUID LEVEL CONTROLLER
DRAIN
INFLUENT
AIR
DRAIN
EFFLUENT TO PRESS. CONTROL VALVE

AIR DISSOLVING TANK

FIGURE 5

The design indicated in Figure 5 was selected after trial because:

1) The Raschig rings in the alternate design collected waste solids.
2) Air dissolving efficiency in the alternate design was low, as evidenced by a lack of bubbles in the flotation tank.
3) The tank used in the selected design had few places where solids could become lodged.
4) There were abundant bubbles produced in the flotation tank when the selected design was tested.

The waste particles entering the flotation cell have two major velocity components. A horizontal component is imparted to the particle by the hydraulic flow; a vertical component results from the buoyant effect of the air bubbles. Therefore, the critical dimensions of the flotation cell are obviously depth and length.

A modified version of Stokes Law:

$$v = \frac{g \left(P_1 - P_d \right) D^2}{18\ u}$$

where

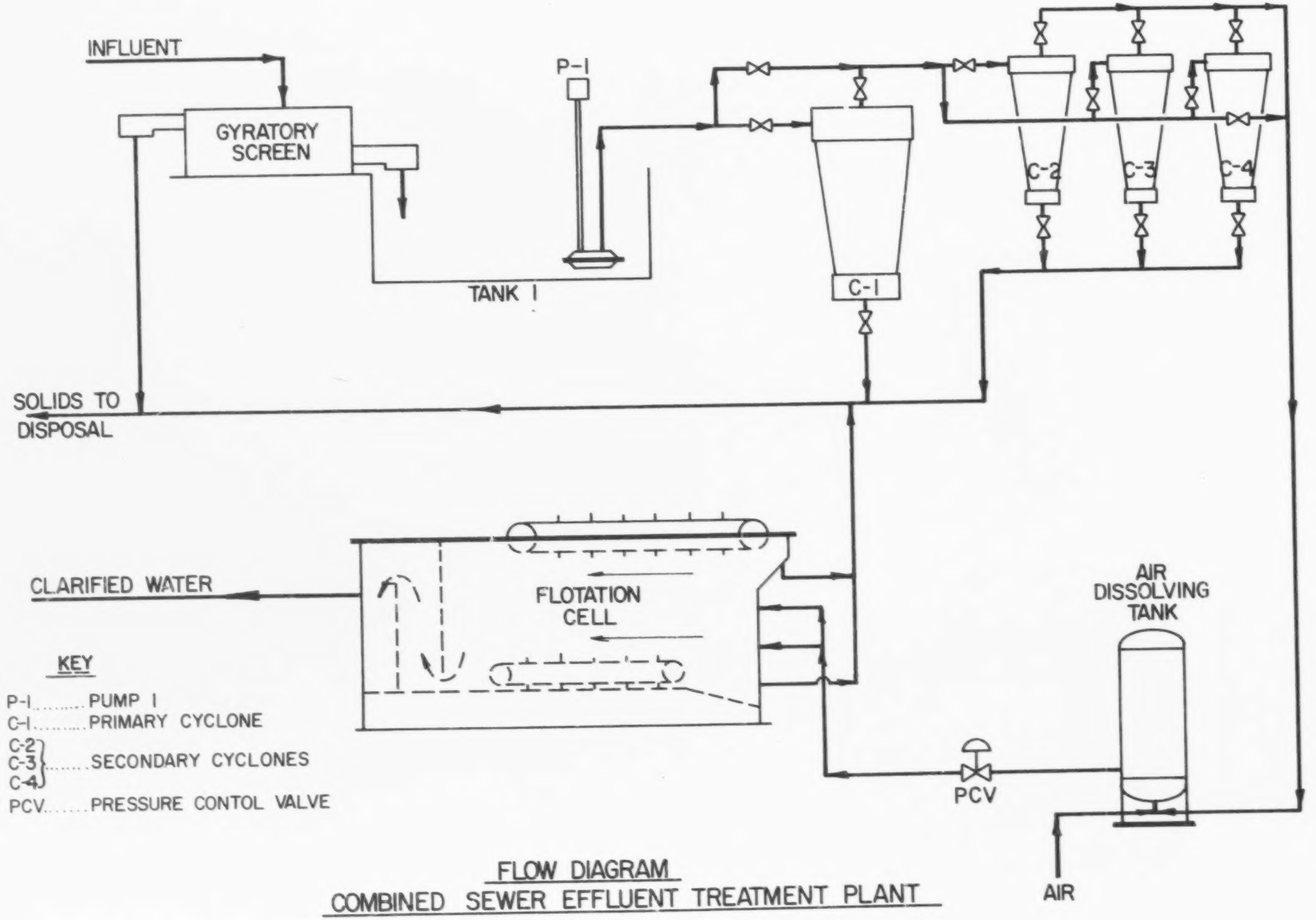
v = terminal velocity of particle
g = acceleration of gravity
P_1 = liquid density
P_d = particle density
D = particle diameter
u = liquid viscosity

indicates that the vertical velocity is a function of particle size and particle density. If the vertical travel of the particle could be decreased, the length of the air flotation tank could also be decreased.

A model of the air flotation tank was constructed using a rectangular design 14 inches deep by 2 feet wide by 5 feet long. The tank was constructed in such a way that the liquid depth, the length of the tank, and the depth of the influent stream could be varied. Flow rates with turndown ratios of 15 to 1 were provided. Optimum suspended solids removal rates occurred for surface loading rates in the neighborhood of 1.5 gallons per square foot of surface per minute. The foam formed was quite easily removed by means of a scraper and appeared to be stable.

On the basis of data obtained from the models of the air flotation tank and air dissolving tank, the demonstration treatment plant (Figure 6) was designed.

The demonstration plant provided primary treatment only. No solids treatment facilities were included. Combined wastewaters first flow over screens to remove the gross debris expected from storm run-offs. Grit and organic matter are removed by hydrocyclones. The liquid overflow from the cyclones then passes through a pressurized air dissolving tank and on to the air flotation cells. In the cells dissolved air comes out of the solution and forms tiny bubbles around the suspended solids


INFLUENT
GYRATORY SCREEN
P-1
TANK 1
C-1
C-2
C-3
C-4
SOLIDS TO DISPOSAL
CLARIFIED WATER
FLOTATION CELL
AIR DISSOLVING TANK
PCV
AIR
KEY
P-1 .... PUMP 1
C-1 .... PRIMARY CYCLONE
C-2, C-3, C-4 .... SECONDARY CYCLONES
PCV .... PRESSURE CONTOL VALVE

FLOW DIAGRAM
COMBINED SEWER EFFLUENT TREATMENT PLANT

FIGURE 6

or immiscible liquid microparticles, which act as nuclei. The bubble-particles float to the surface and form thin mats which are removed by scrapers. Dense materials which escape removal in the cyclones sink to the bottom of the flotation cell and are scraped into a collection trough. Effluent waters may be further treated or discharged into a receiving stream or river; the solids collected may be passed to conventional sludge equipment.

SECTION VI

DESIGN DETAILS
OF
MAJOR COMPONENT PARTS

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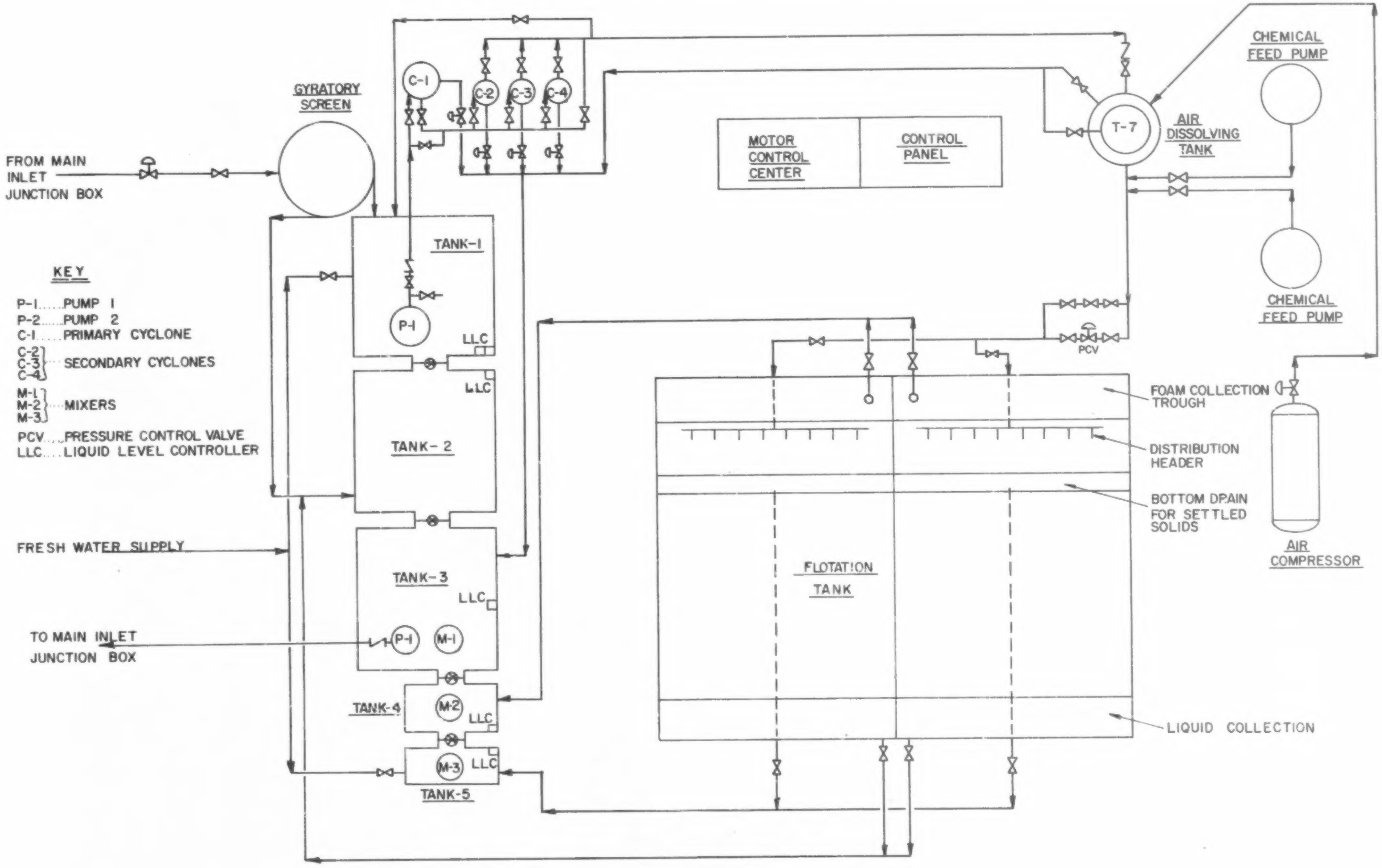
DESIGN DETAILS
OF
MAJOR COMPONENT PARTS

Figure 6a is a detailed diagram of the dissolved-air flotation system as contructed at Fort Smith, Arkansas. Incoming waste water was screened by a 48-inch gyratory screen, and the screened waste water was then dumped into Tank 1. The liquid level was controlled by a flow control valve at the outlet from the Fort Smith sewage distribution box.

A multi-stage vertical turbine pump removed waste water from Tank 1 and forced it through two banks of hydrocyclones at a design rate of 350 GPM. The primary cyclone was 12 inches in diameter and was sized to remove particles as small as 50 microns in diameter. Partially degritted water from the primary cyclone was directed to a bank of three secondary cyclones operated in parallel. The secondary cyclones were 10 inches in diameter and were each capable of handling 150 GPM of flow. The secondary cyclones were designed to remove particles as small as 25 microns in diameter. The design pressure drop across the secondary cyclones was approximately 20 pounds per square inch.

The two-stage cyclone design was selected for two reasons:

1) The primary cyclone was included to remove the larger dense particles, because it was feared that these


GYRATORY SCREEN
FROM MAIN INLET JUNCTION BOX
C-1
C-2
C-3
C-4
MOTOR CONTROL CENTER
CONTROL PANEL
T-7
AIR DISSOLVING TANK
CHEMICAL FEED PUMP
CHEMICAL FEED PUMP
TANK-1
P-1
LLC
KEY
P-1.....PUMP 1
P-2.....PUMP 2
C-1.....PRIMARY CYCLONE
C-2, C-3, C-4 ... SECONDARY CYCLONES
M-1, M-2, M-3 ... MIXERS
PCV.....PRESSURE CONTROL VALVE
LLC.....LIQUID LEVEL CONTROLLER
TANK-2
LLC
PCV
FOAM COLLECTION TROUGH
DISTRIBUTION HEADER
BOTTOM DRAIN FOR SETTLED SOLIDS
AIR COMPRESSOR
FRESH WATER SUPPLY
TANK-3
LLC
FLOTATION TANK
TO MAIN INLET JUNCTION BOX
P-1
M-1
TANK-4
M-2
LLC
LIQUID COLLECTION
M-3
LLC
TANK-5

DETAILED DIAGRAM DEMONSTRATION PILOT PLANT

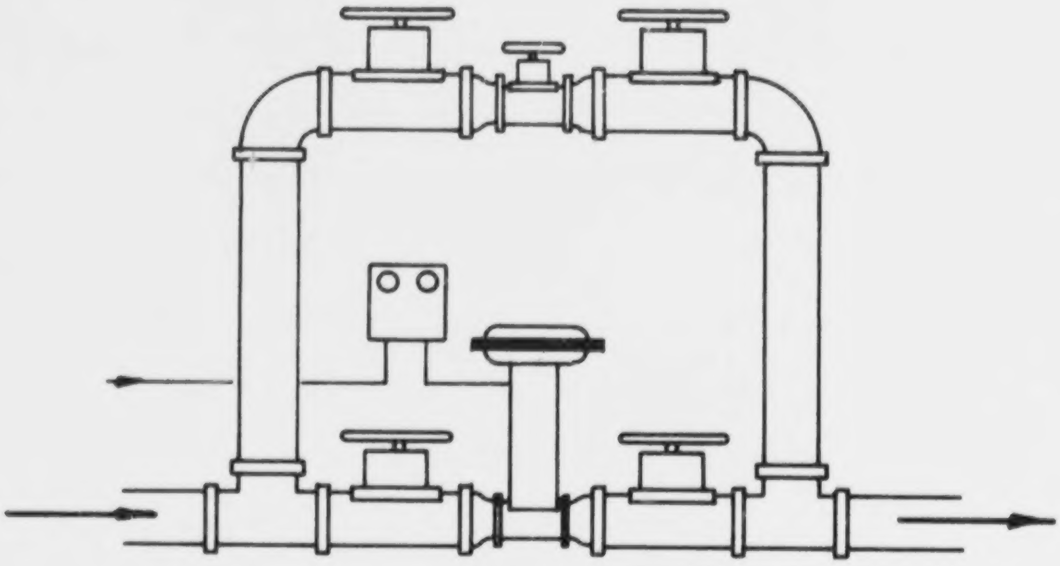
(FIGURE 6a)

particles might tend to overload the secondary cyclones and clog the apex valves.

2) Experimental flexibility was needed so that various cyclone combinations could be studied to obtain the maximum removal of dense particles.

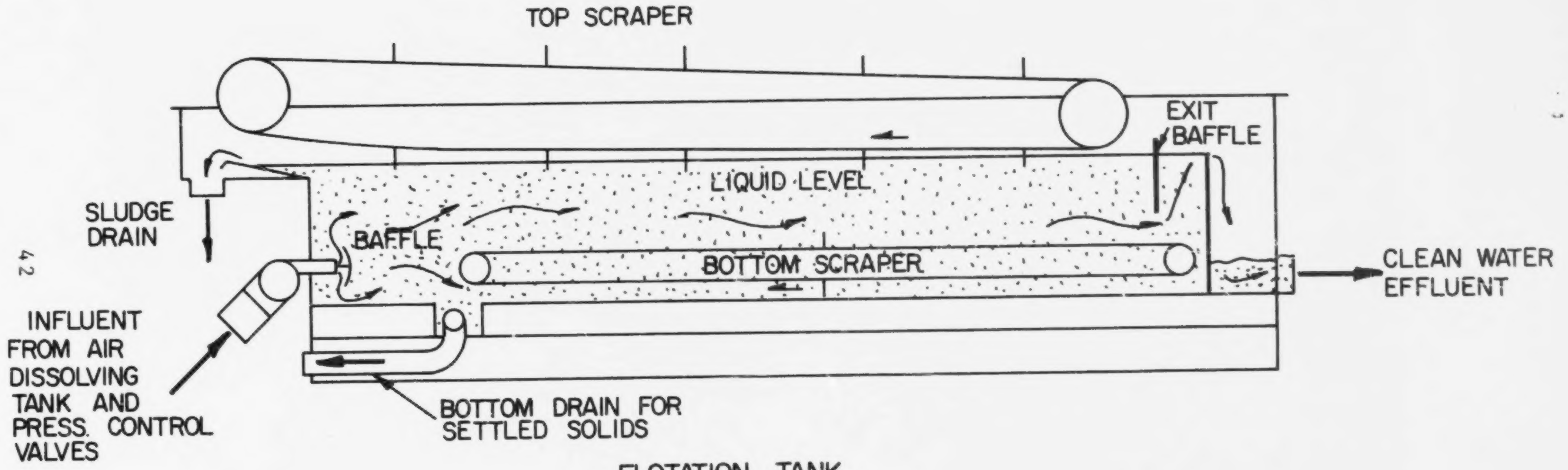
The hydrocyclone overflow passed through the air dissolving tank and on to a pressure control device consisting of two, 2-inch diaphragm valves. One valve was operated by a pneumatic activator; the other valve was manually operated (Figure 7). This dual operational capacity was included for testing purposes. For flow rates greater than 350 GPM, both control valves were necessary to handle the flow. Wastes entered the air flotation tank through a 6-inch header with 2-inch nozzles evenly spaced along it and passing through the end wall of the tank (Figure 8). The air flotation tank was 20 feet wide and 15 feet long and was divided into two cells, each 10 feet wide, for greater experimental flexibility. The cell wall height, 29-1/4 inches, was dictated by the size and availability of the chain sprockets used for the foam scraper mechanism. The flotation chamber of each cell was 10 feet wide by 12 feet long; the remaining 3 feet of length was used as a foam trough and liquid effluent collector.

Solid and liquid effluent wastes from the air flotation tank were piped into Tanks 2, 3, 4, and 5, for collection, sampling and disposal. Disposal was accomplished by remixing and returning the wastes to the Fort Smith sewage distribution box.



THE PRESSURE CONTROL VALVES

FIGURE 7


TOP SCRAPER
EXIT BAFFLE
LIQUID LEVEL
SLUDGE DRAIN
BAFFLE
BOTTOM SCRAPER
CLEAN WATER EFFLUENT
INFLUENT FROM AIR DISSOLVING TANK AND PRESS. CONTROL VALVES
BOTTOM DRAIN FOR SETTLED SOLIDS

FLOTATION TANK

FIGURE 8

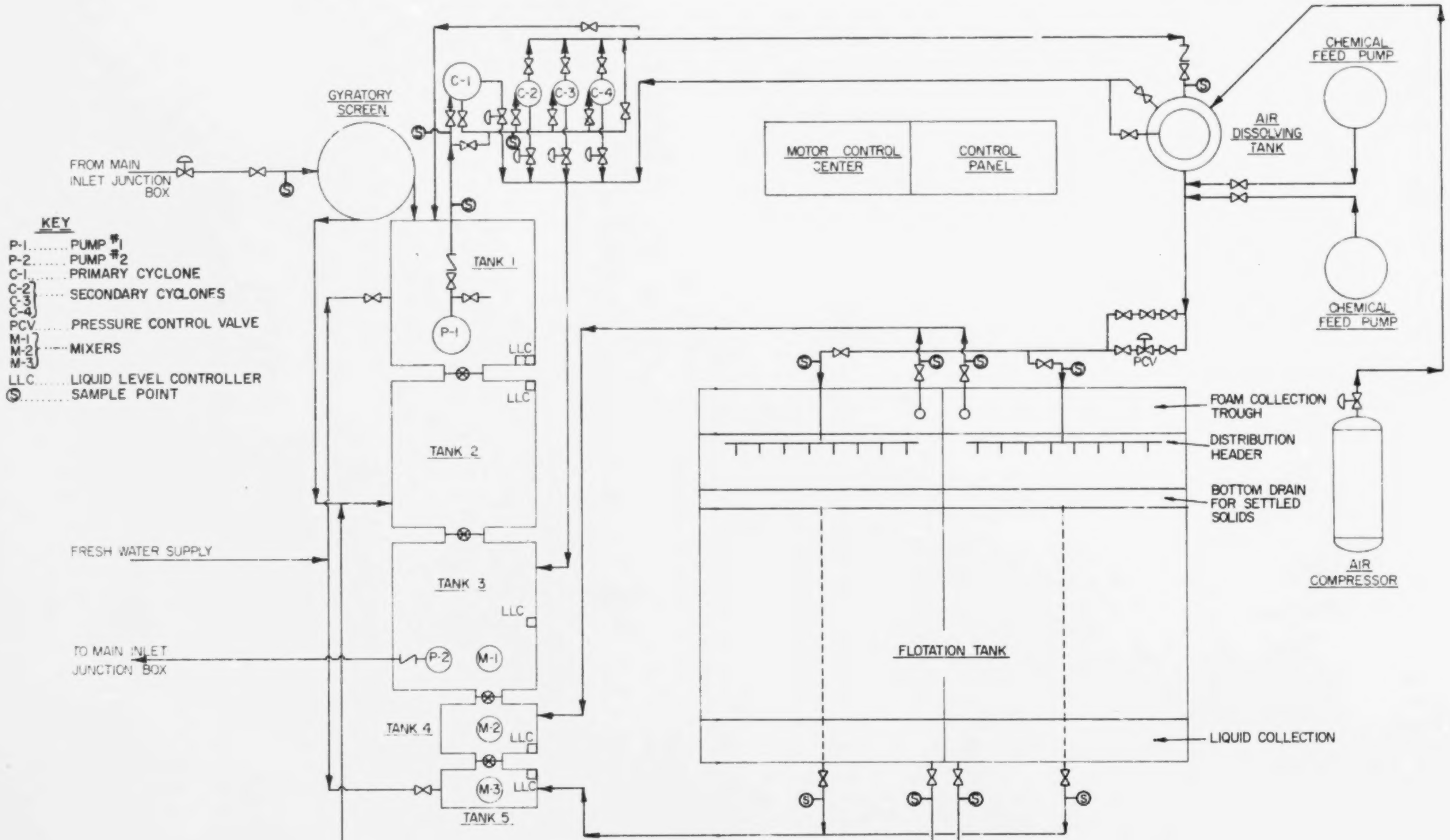
SECTION VII

SAMPLING AND INITIAL PLANT MODIFICATIONS

SAMPLING AND INITIAL PLANT MODIFICATIONS

Following the commissioning of the pilot plant and the initial start-up exercises, a program of sample-point and sampling-technique evaluation was initiated. Figure 9 is a schematic diagram of the sampling points finally selected for the demonstration plant. Note that sampling points are located so that the efficiency of each major piece of equipment can be ascertained. Most sampling points were controlled by a diaphragm valve. In most cases composite samples were accumulated every 1/2 hour on a 4- or 8-hour schedule. Grab samples were also used as the need arose. Samples were placed in gallon jugs and immediately iced to slow chemical and biological action.

Sampling difficulties with the liquid effluent or overflow from the cyclones made it impossible to conduct detailed material balances for evaluation of performance. In some cases it was suspected that the cyclones were breaking up part of the larger or more fragile solids. Initially, sampling was done from 1/2 inch valves which drained from the center of the pipe installed immediately down-stream of the cyclone overflows. Because of the difficulty experienced in obtaining duplicate samples, it was theorized that the swirling motion imparted to the liquid as it passed through the cyclones was carried on by the liquid as it left the cyclone causing the solid


FROM MAIN INLET JUNCTION BOX
GYRATORY SCREEN
KEY
P-1........PUMP #1
P-2........PUMP #2
C-1........PRIMARY CYCLONE
C-2, C-3, C-4 ....SECONDARY CYCLONES
PCV........PRESSURE CONTROL VALVE
M-1, M-2, M-3 ....MIXERS
LLC........LIQUID LEVEL CONTROLLER
S........SAMPLE POINT
C-1
C-2
C-3
C-4
S
TANK 1
P-1
LLC
TANK 2
LLC
TANK 3
LLC
P-2
M-1
TANK 4
M-2
LLC
M-3
LLC
TANK 5
FRESH WATER SUPPLY
TO MAIN INLET JUNCTION BOX
MOTOR CONTROL CENTER
CONTROL PANEL
AIR DISSOLVING TANK
CHEMICAL FEED PUMP
CHEMICAL FEED PUMP
PCV
FOAM COLLECTION TROUGH
DISTRIBUTION HEADER
BOTTOM DRAIN FOR SETTLED SOLIDS
FLOTATION TANK
LIQUID COLLECTION
AIR COMPRESSOR

SAMPLE POINT DIAGRAM
DEMONSTRATION PILOT PLANT

(FIGURE 9)

particles to remain near the periphery of the flow rather than being mixed thoroughly with the liquid as it passed through the pipe. Additionally, some of the duplication difficulties were undoubtedly due to rapidly changing waste characteristics.

Laboratory analysis of the samples were performed to ascertain the following:

1) pH.
2) Turbidity.
3) Total suspended solids.
4) Volatile suspended solids.
5) Total solids.
6) Total volatile solids.
7) Total nitrogen.
8) Total phosphates.
9) Biochemical oxygen demand (BOD).

The laboratory analyses were accomplished using the methods outlined in "Standard Methods for the Examination of Water and Waste Water," 12th Edition, published jointly by the American Public Health Association, the American Waterworks Association, and The Water Pollution Control Federation (32). Laboratory quality control procedures suggested by the Taft Engineering Center, FWPCA, Cincinnati, Ohio, were used.

Two modifications added significantly to the success of the demonstration. These included (1) change of the point of influent selection from the Fort Smith sewage distribution box to eliminate much of the industrial waste, and (2) the addition of a baffle plate in the flotation cell to eliminate large bubbles.

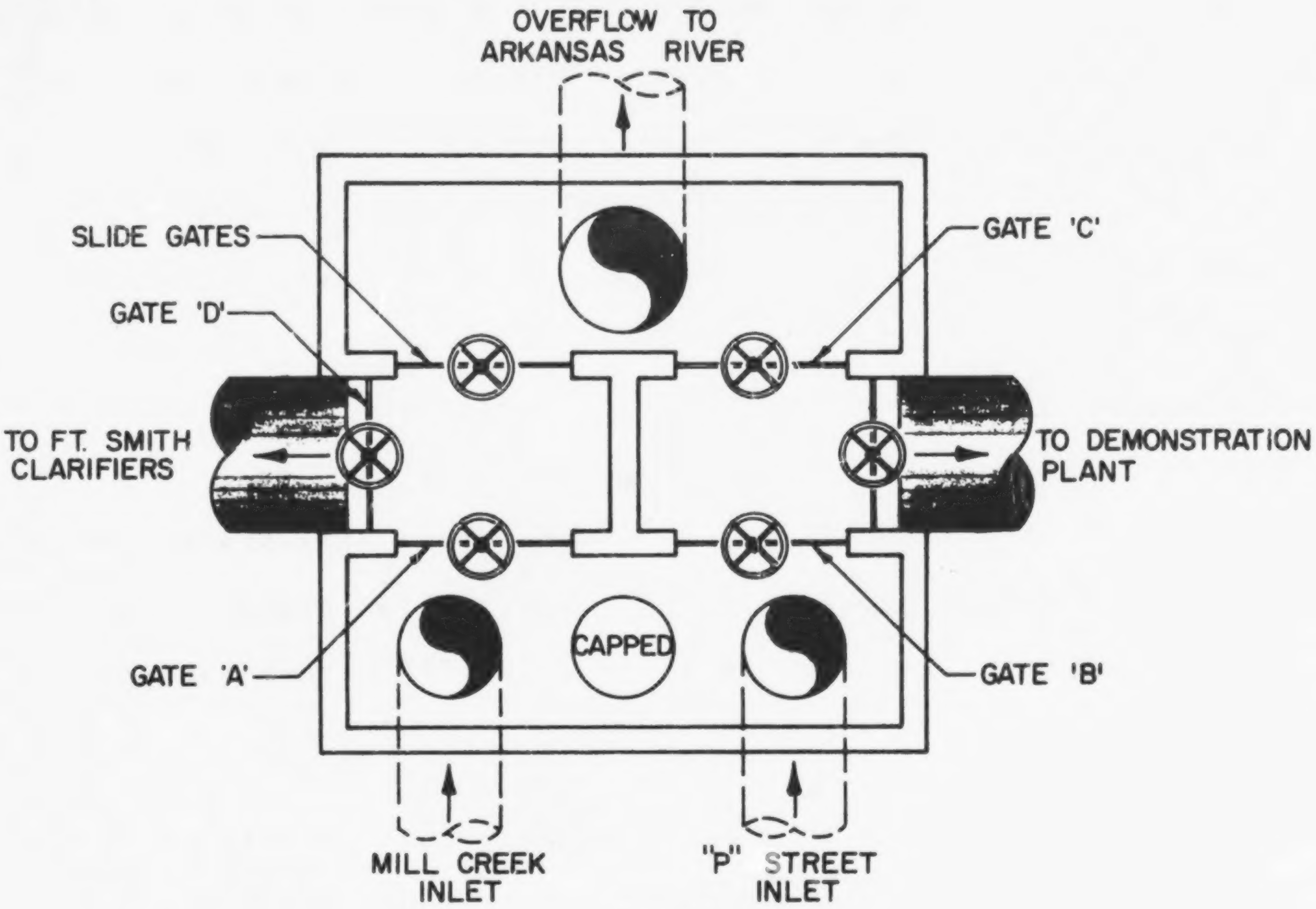
The wastes arriving at the distribution box at Fort Smith's sewage disposal plant consisted of a mixture of industrial wastes and domestic sewage. Laboratory analyses showed wide variations in both pH and total suspended solids. Some of these variations are illustrated in the appendix. The industries discharging waste into the sewage system at Fort Smith include a fertilizer plant, packing houses, a slaughterhouse, a major appliance manufacturer, and several metal plating and fabricating shops. These industries cause Fort Smith sewage to vary quite drastically from domestic sewage in both physical and chemical makeup. At times acid wastes reduced the pH to a value of 3.2. Heavy intermittent loads of hair, blood,and animal greases were also noted.

Wastes from two Fort Smith collection systems, Mill Creek and "P" Street, were mixed in the distribution box. The Mill Creek sewage main carried primarily domestic wastes, but the major appliance manufacturing plant and the slaughterhouse also discharged their wastes into the Mill Creek system.

The "P" Street collection system contained a mixture of domestic wastes and heavy industrial wastes which was characterized by a high percentage of nonvolatile suspended solids and a widely varying pH.

Wastes flowed from the distribution box to the Fort Smith clarifiers when gates "A" and "D" were opened and also flowed to the demonstration plant when gates "B" and "C" were opened (Figure 10). To prevent the "P" Street wastes from entering the demonstration plant the ends of two 4-inch pipes were inserted deep into the Mill Creek inlet. The other ends of the pipes were passed through two flanged holes in a 12-inch-wide steel plate installed beneath gate "B" (Figure 11). This plate raised gate "B" so its top edge was 12 inches above the top of closed gate "A". The mixture of Mill Creek and "P" Street wastes overflowed gate "A" to the clarifiers while the hydraulic head thus produced forced Mill Creek wastes through the 4-inch pipes into the demonstration plant. The modification was effective in eliminating "P" Street wastes from the demonstration plant influent.

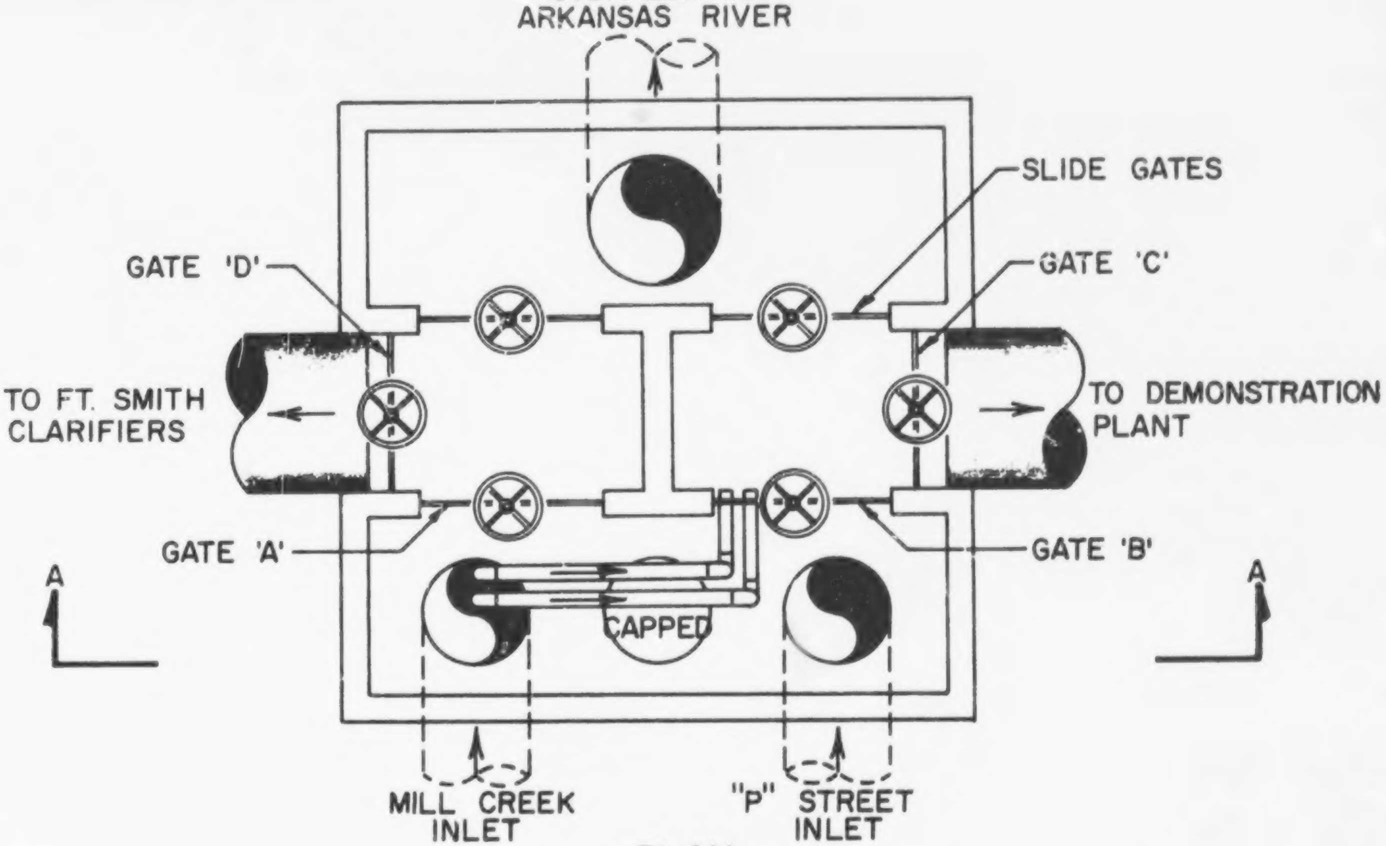
The air flotation cell as originally built permitted large bubbles of air to rise through the liquid and disrupt the mat of floating solids. A baffle plate was installed above the liquid inlet nozzles to trap and vent these bubbles (Figure 12). It should be possible to accomplish the venting by inverting the inlet header to the air flotation cell so that the waste liquid exits the inlet header from the bottom rather than the top. The large bubbles of air would then rise to the top of the inlet header where they could be vented with a 1/2-inch pipe. Figure 13a shows the inlet header as built; Figure 13b shows the recommended modification.


OVERFLOW TO ARKANSAS RIVER
SLIDE GATES
GATE 'D'
GATE 'C'
TO FT. SMITH CLARIFIERS
TO DEMONSTRATION PLANT
GATE 'A'
CAPPED
GATE 'B'
MILL CREEK INLET
"P" STREET INLET

PLAN

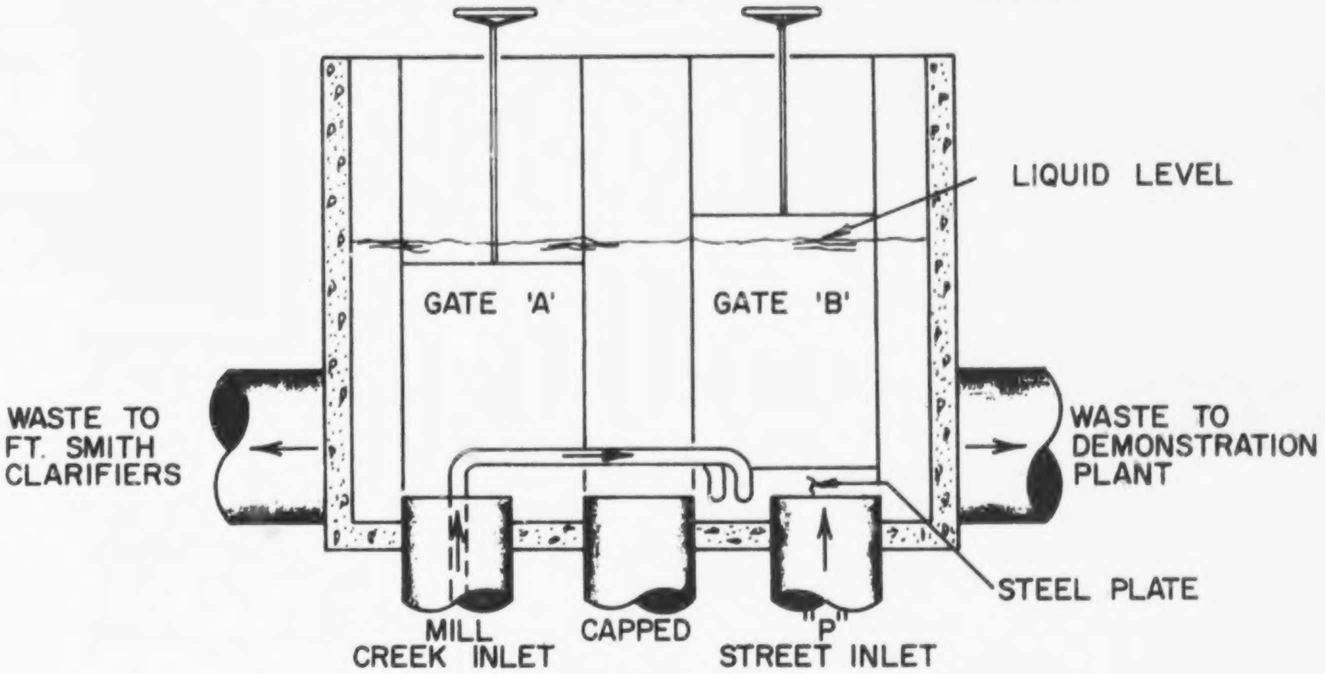
DISTRIBUTION BOX AT THE FT. SMITH "P" STREET POLLUTION CONTROL FACILITY

FIGURE 10


OVERFLOW TO ARKANSAS RIVER
SLIDE GATES
GATE 'D'
GATE 'C'
TO FT. SMITH CLARIFIERS
TO DEMONSTRATION PLANT
GATE 'A'
GATE 'B'
A
A
CAPPED
MILL CREEK INLET
"P" STREET INLET

PLAN

MODIFICATION OF DISTRIBUTION BOX AT FT. SMITH "P" STREET POLLUTION CONTROL FACILITY


LIQUID LEVEL
GATE 'A'
GATE 'B'
WASTE TO FT. SMITH CLARIFIERS
WASTE TO DEMONSTRATION PLANT
STEEL PLATE
MILL CREEK INLET
CAPPED
"P" STREET INLET

SECTION A-A

FIGURE 11

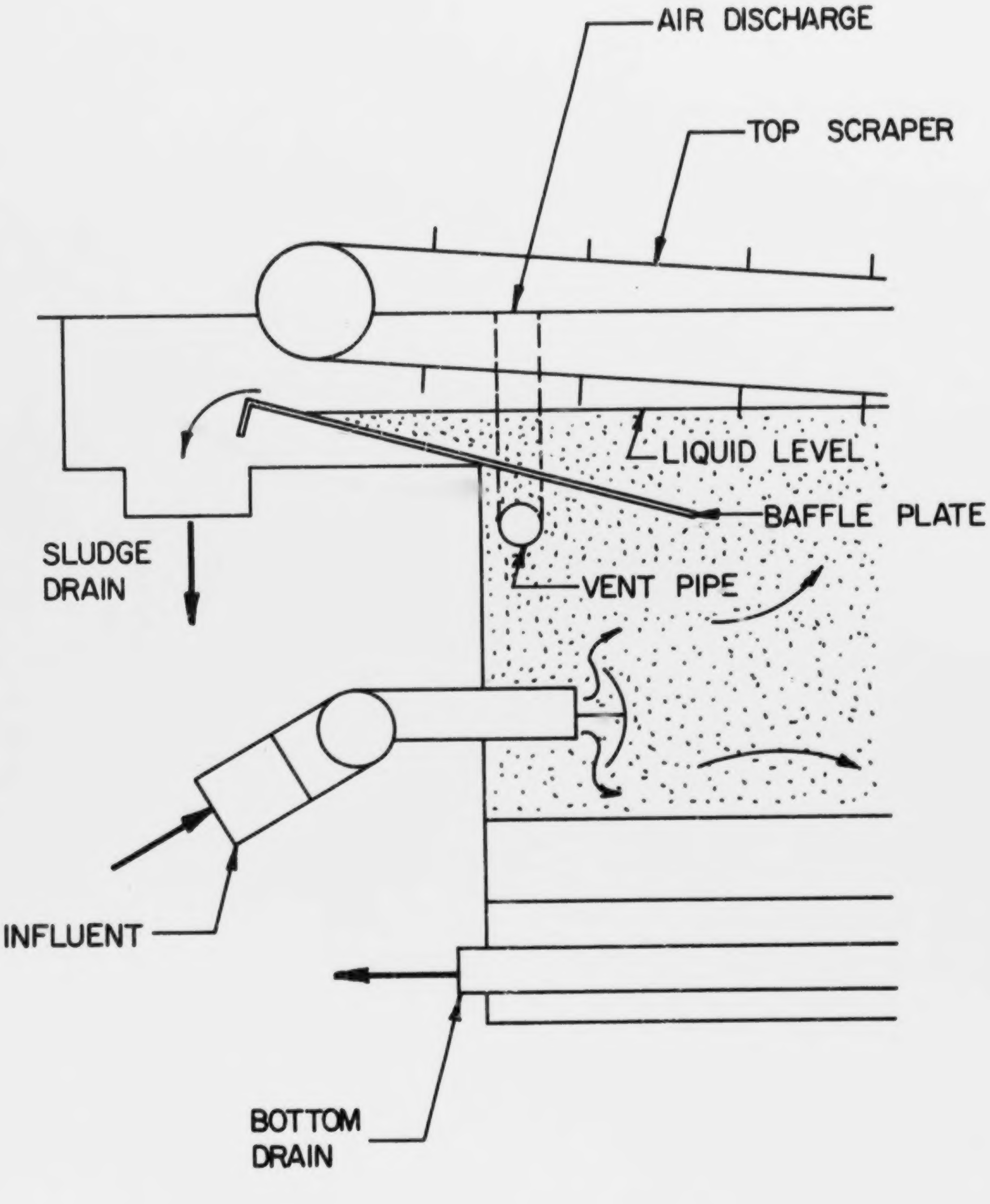
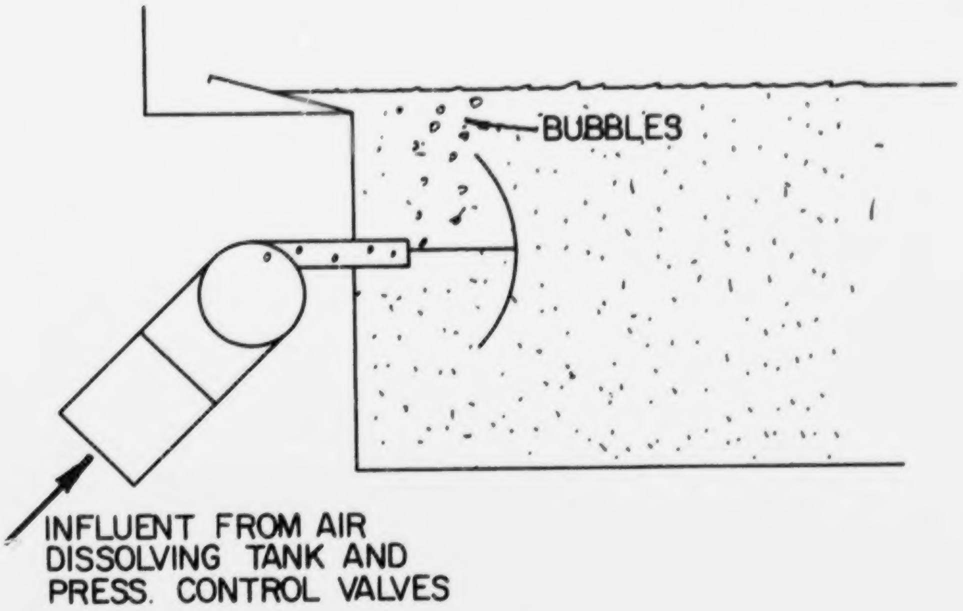
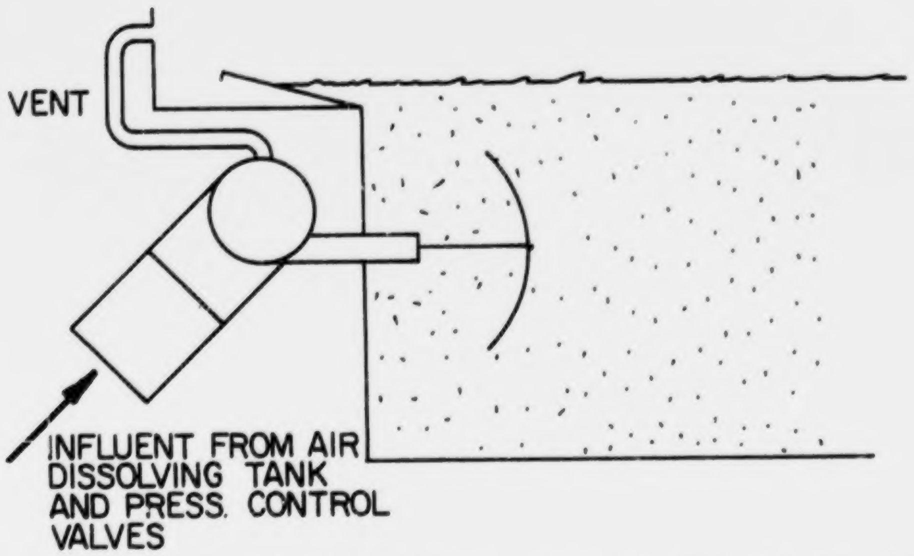

AIR DISCHARGE
TOP SCRAPER
LIQUID LEVEL
BAFFLE PLATE
SLUDGE DRAIN
VENT PIPE
INFLUENT
BOTTOM DRAIN

FIGURE 12


BUBBLES
INFLUENT FROM AIR DISSOLVING TANK AND PRESS. CONTROL VALVES

(a) INLET HEADER AS BUILT


VENT
INFLUENT FROM AIR DISSOLVING TANK AND PRESS. CONTROL VALVES

(b) SUGGESTED DESIGN FOR INLET HEADER

FIGURE 13

During commissioning and start-up activities in the fall of 1967 it was noted that rain beat some of the particles down out of the floating mat; extremely high winds had a similar effect. To protect the foam, a Visqueen cover was installed over the entire air flotation tank. Location of a dissolved-air flotation unit so as to take advantage of the protection offered by already existing walls and cover should be considered.

Photographs of the demonstration plant appear in Appendix A. Appendix B shows the Fort Smith drainage area, and Appendix C is a resume of construction costs.

SECTION VIII

TESTING AND EVALUATION

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TESTING AND EVALUATION

Two groups of tests were scheduled for completion at the Fort Smith demonstration plant. The first group, called the basic data collection tests, were selected to perfect operating techniques and parameters for the plant. The tests included operation of the plant with various air dissolving pressures, determination of optimum air feed rates, and the determination of optimum waste flow rates. Various chemical flocculating agents were tried in jar tests. Results of the jar tests were later used in determining the best chemicals for use in the demonstration plant. During the period of basic data collection, sampling and laboratory analysis techniques were evaluated. Retention time studies using tracer dyes were also performed.

Upon completion of the basic data collection tests the second group of tests were scheduled. The second group of tests included:

1) Equipment testing.
2) Chemical testing.
3) Rain event testing.

Rain event testing had precedence over all other testing; arrangements were made so that personnel were on call whenever a storm event occurred, even if this event occurred after normal working hours or during weekends.

Table 2 lists the removal percentages of the various waste components when different equipment combinations were used. No chemical aids to flocculation were used during this series of tests.

As indicated in Table 2, the equipment combinations in this phase of operations were: (1) All the separatory equipment including screen, four cyclones, and air flotation tank; (2) The screen and air flotation tank; (3) The screen, primary cyclone, and air flotation tank; (4) The screen, three secondary cyclones, and air flotation tank; (5) The screen, two secondary cyclones, and air flotation tank. A one-way analysis of variance was performed on the results. The computations and resulting analysis are shown in Tables D-5, D-6, and D-7, in Appendix, D, pages D-48 through D-58.

These analysis show that:

1) There is a statistically-significant difference between the suspended solids removal rates. The best removal rates were obtained when all the separatory equipment was in use and when two secondary cyclones and the flotation tank were in use.
2) Any differences between the rates of BOD reduction are due to chance, and changes in auxiliary separatory equipment do not significantly affect BOD reduction rates.

TABLE 2

PERCENT REMOVAL OF SEWAGE COMPONENTS WHEN DIFFERENT EQUIPMENT COMBINATIONS WERE USED

(NO CHEMICAL FLOCCULANTS)

	Removal of Suspended Solids		Reduction of BOD		Removal of Total Solids		Removal of Total Phosphorous		Removal of Total Nitrogen	
Equipment Used	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.
All Equipment	62	59 to 65	26	18 to 34	17	7 to 27	14	8 to 20	4	3 to 6
Screen & Flotation Cell	49	42 to 57	27	3 to 65	27	0 to 70				
Screen, Primary Cyclone & Flotation Cell	49	43 to 55	35	16 to 54	16	0 to 65				
Screen, 3 Secondary Cyclones & Flotation Cell	53	46 to 70	36	15 to 57	23	13 to 33				
Screen, 2 Secondary & Flotation Cell	65	57 to 73	41	5 to 80	23	20 to 26				

$\overline{X}$ = Arithmetic Mean
95% C.I. = 95% Confidence Interval

Because total nitrogen and total phosphorus content in the waste treated at the demonstration pilot plant was primarily due to dissolved solids, a cursory examination of the data is sufficient to indicate that there is no significant difference in the removal rates of these components in the various operational modes. Further examination shows that the total nitrogen phosphate removal was 14 percent; Table 2 indicates the 95 percent confidence intervals for the removal rates in both cases.

The results indicate that the dissolved air flotation system is capable of removing up to 65 percent of suspended solids after the influent waste has been screened to remove gross solids.

The BOD reduction varies from 26 to 41 percent with a mean of 33 percent. This compares favorably with the removal by conventional primary treatment plants. The BOD and total solids removal rates can be attributed to the removal of suspended solids in the influent waste.

A chemical testing program was accomplished. Letters of inquiry sent to various chemical companies brought offers of technical assistance in the initial testing of the chemical additives. Jar tests were used to reduce the wide field of possibilities, and the most promising chemicals were tried in conjunction with each other in attempts to achieve even better results. Results of the jar tests were applied to full scale demonstration plant operation.

The chemical companies volunteering to participate in the program included:

1) Calgon Corporation.
2) Dow Chemical Company.
3) Drew Chemical Corporation.
4) Pennsalt Chemicals Corporation.
5) Tretolite Division of etrolite Corporation.

Letters of inquiry to several other manufactures of waste water chemical additives brought no response.

In almost all cases, the chemical additives were used as "polishing agents" to improve the performance of the alum or lime used as the primary or main flocculant. The data obtained are by no means exhaustive. In some cases not enough chemical additive was available for extensive testing. In other cases equipment problems, corrosion, and plugging prevented attempts to inject the chemicals into the waste stream.

Chemical feed rates were usually determined by first adjusting the alum feed rate to give the least turbid effluent, then adding increments of polishing agent chemicals to further decrease turbidity. Effects of feed rate changes were apparent in the effluent waste stream within 10 minutes of the change. Because of the extremely variable strength and pH of the influent waste, it was impossible to maintain optimum chemical feed rates for longer than 1/2 hour. Operating procedure was to determine optimum feed rates at the start of a test run and continue the test without changes in this feed rate.

Some polishing agents exhibited a synergistic effect in combination with alum so that the alum feed rate could be reduced. Ferric chloride is an example.

Data obtained for ferric chloride and a combination of ferric chloride, alum, and Tretolite FR-50 (a polyelectrolyte) are the result of a rather limited testing program. The extremely corrosive ferric chloride made extensive testing impossible. Ferric chloride was fed to the system by siphoning it from plastic-lined drums into Tank 1. When tests using lime were performed, lime was also introduced into the waste stream by siphoning into Tank 1. Tests using alum and the polyelectrolytes indicated that the best point of injection was after the air dissolving tank. This may well have been the case with ferric chloride and lime also, and better results might have been obtained if they had been injected after the air dissolving tank.

Table 3 lists the results obtained when various chemical flocculation aids were used during periods of no rain. In all cases all the separatory equipment was in use except as noted.

Chemical feed rates varied, as previously noted, but ranged as follows:

TABLE 3

PERCENT REMOVAL OF THE VARIOUS COMPONENTS WHEN DIFFERENT CHEMICAL TREATMENTS WERE USED. ALL MECHANICAL SEPARATORY EQUIPMENT WAS ON STREAM.

	Removal of Suspended Solids		Reduction of BOD		Removal Total Solids		Removal of Total Phosphorous		Removal Total Nitrogen	
Chemicals Used	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.
No Chemicals	62	59 to 65	26	18 to 34	17	7 to 27	29	0 to 100	13	10 to 16
Alum Only	64	22 to 100	47	22 to 71	19	9 to 30	53	29 to 77	5	2 to 8
Alum + Tretolite FR-50	69	59 to 80	53	39 to 66	34	16 to 59	43	27 to 59	5	2 to 8
Alum + Dow SA118.1A	93	88 to 98	63	45 to 81	31	16 to 46	34	12 to 56	7	0 to 10

There is insufficient data for full statistical analysis of the following results:

$FeCl_3$ Only	90	84 to 96	42	8 to 76	19	0 to 65	73	30 to 100	6	0 to 50
$FeCl_3$ + Alum + Tretolite FR-50	95	89 to 100	86	53 to 100	58	15 to 95	80	35 to 100	27	0 to 45
Alum + Tretolite FR-50 (Screen, 3 Secondary Cyclones & Flotation Tank)	89	70 to 100	68	25 to 100	60	15 to 100				

$\overline{X}$ = Arithmetic Mean
95% C.I. = 95% Confidence Interval

1) Alum - 15 mg/l to 175 mg/l.
2) Tretolite FR-50 - 1 mg/l to 30 mg/l.
3) Dow SA1188.1A - 1 mg/l to 10 mg/l.
4) Ferric Chloride - 10 mg/l to 60 mg/l.

Computations and the resulting analyses are shown in Appendix D, pages D-70 through D-88 and in Tables D-8, D-9 , D-10, D-11.

The analyses show that:

1) Of the chemicals tried, alum plus Dow SA1188.1A provides the most effective treatment for suspended solids removal.

2) There is no apparent statistical difference between the BOD reduction rates, the total solids removal rates, the total phosphorus and the total nitrogen removal rates for the chemical treatments listed in Table 3.

The demonstration plant was operated during every rain event with total precipitation of 0.1 inch or more. Results of these operations are shown in Table 4. Chemical feed rates were varied to yield the least turbid effluent and then left at that rate for the remainder of the storm event or sample period. Typical feed rates were: (1) alum - 5 mg/l to 175 mg/l; (2) Tretolite FR-50 - 1 mg/l to 30 mg/l.

Note that Table 4 shows that treatment with alum resulted in poorer removal rates than no treatment at all. However, there were so few rain events that the computed means have a wide confidence interval (essentially, there can be only a very low confidence in the answer). The statistical analyses found in Appendix D, Tables D-1, D-2, D-3, and D-4, pages D-21 through D-38 bear this out

The analyses show that:

1) Suspended solids removal during storm events is not a function of the treatment or chemicals used.
2) There was no significant difference in BOD reduction between treatments using no chemicals and treatments using alum. However, BOD reduction during the operations using alum plus Tretolite FR-50 was significantly better than the other two treatments.
3) Alum plus Tretolite FR-50 was significantly better in reducing total solids than was treatment with alum or without chemicals.

TABLE 4

PERCENT REMOVALS OF THE VARIOUS COMPONENTS DURING RAIN EVENTS. ALL MECHANICAL SEPARATORY EQUIPMENT WAS ON STREAM.

Modes of Operation	Removal of Suspended Solids		Reduction of BOD		Removal of Total Solids		Removal of Total Phosphorous		Removal of Total Nitrogen	
	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.	$\overline{X}$	95% C.I.
No Chemicals	69	40 to 98	40	8 to 76	24	11 to 57	48	6 to 80	4	0 to 50
Alum Only	56	34 to 78	35	9 to 61	36	23 to 48	30	2 to 72	-	----
Alum + Tretolite FR-50	84	82 to 86	73	67 to 79	52	43 to 60	74	56 to 92	6	0 to 45

$\overline{X}$ = Arithmetic Mean

95% C.I. = 95% Confidence Interval

4) Removal rates of total phosphorus were unaffected by chemical treatment or lack of chemical treatment.

5) There was insufficient data concerning total nitrogen removals to make any analysis.

A resume of reductions in suspended solids, BOD, and total solids appears in Table 5.

Table 6 lists some of the various components of Fort Smith sewage during both dry weather and rain events and compares them to the content of a typical medium strength sewage (33, 34).

During dry weather the total solids content of Fort Smith sewage is about 25 percent less than typical waste, however, the organic content of each waste is nearly the same. Fort Smith's dry weather sewage contains a greater percentage of suspended solids, but again the percentages of volatile content are much the same.

The high phosphate content of dry weather sewage may be due to the discharge of waste from a fertilizer plant into the Mill Creek force main. A satisfactory explanation for the low total nitrogen content could not be found.

During rain events both total solids and suspended solids content increased. In many other cities solids concentration decreases during rain events. The organic fraction decreased for both total and suspended solids. Dilution of phosphate content was also observed.

TABLE 5

PERCENT REMOVAL OF SEVERAL COMPONENTS WHEN DIFFERENT EQUIPMENT COMBINATIONS WERE USED

(No Chemicals)

	Removal Total Suspended Solids		Reduction BOD		Removal Total Solids	
Equipment Used	$\bar{X}$	95% C.I.	$\bar{X}$	95% C.I.	$\bar{X}$	95% C.I.
Screen & Flotation Cell	49	42 to 57	27	3 to 65	27	0 to 70
Screen, Primary Cyclone & Flotation Cell	49	43 to 55	35	16 to 54	16	0 to 65
Screen, 3 Secondary Cyclones & Flotation Cell	53	46 to 70	36	15 to 57	23	13 to 33
Screen, 2 Secondary Cyclones & Flotation Cell	65	57 to 80	41	5 to 80	23	20 to 26

PERCENT REMOVAL OF SEVERAL COMPONENTS WHEN DIFFERENT CHEMICAL TREATMENTS WERE USED. ALL MECHANICAL SEPARATORY EQUIPMENT WAS ON STREAM.

	Removal Total Suspended Solids		Reduction BOD		Removal Total Solids	
Chemical Used	$\bar{X}$	95% C.I.	$\bar{X}$	95% C.I.	$\bar{X}$	95% C.I.
No Chemicals	62	59 to 65	26	18 to 34	17	7 to 27
Alum Only	64	22 to 100	47	22 to 71	19	9 to 30
Alum + Tretolite FR-50	69	59 to 80	53	39 to 66	34	16 to 51
Alum + Dow SA1188.1A	93	88 to 98	63	45 to 81	31	16 to 46

There is insufficient data for full statistical analysis of the following:

$FeCl_3$ Only	90	84 to 96	42	8 to 76	19	0 to 65
$FeCl_3$ + Alum + Tretolite FR-50	95	89 to 100	86	53 to 100	58	15 to 95
*Alum + Tretolite FR-50	89	70 to 100	68	25 to 100	60	15 to 100

* Primary Cyclone not used in this instance.

PERCENT REMOVAL OF SEVERAL COMPONENTS DURING RAIN EVENTS.

ALL MECHANICAL SEPARATORY EQUIPMENT WAS ON STREAM.

	Removal Total Suspended Solids		Reduction BOD		Removal Total Solids	
Modes of Operation	$\bar{X}$	95% C.I.	$\bar{X}$	95% C.I.	$\bar{X}$	95% C.I.
No Chemicals	69	40 to 98	40	8 to 76	24	11 to 57
Alum Only	56	34 to 78	35	9 to 61	36	23 to 48
Alum + Tretolite FR-50	84	82 to 86	73	67 to 79	52	43 to 60

Tables 2, 3, 4, and 5 contain abbreviations for several statistical terms. They are;

$$\bar{X}=\frac{\Sigma x_i}{N}$$

Where $\bar{X}$ = sample arithmetic mean,

x_i = experimental values, and

N = number of values.

95% C.I. = The 95% Confidence Interval. The data indicates there is a 95% probability (chance) that the true or population arithmetic mean lies between these two values inclusive. Alternatively, there is a 5% probability that the true mean lies outside the given set of values.

TABLE 6

COMPARISON OF SEWAGE STRENGTHS *

Component	Fort Smith Sewage		Typical Medium Strength Sewage (33, 34)
	Dry Weather mg/1	Rain Events mg/1	mg/1
Total Solids	621	880	880
Total Volatile Solids	349	396	420
$\frac{\text{Total Volatile Solids}}{\text{Total solids}} \times 100$	56%	45%	52%
Suspended Solids	272	534	200
Volatile Suspended Solids	195	273	135
$\frac{\text{Suspended Solids}}{\text{Total Solids}} \times 100$	44%	61%	25%
$\frac{\text{Volatile Suspended Solids}}{\text{Suspended Solids}} \times 100$	72%	51%	68%
BOD	174	212	210
Total Nitrogen	18	16	40
Total Phosphate	40	28	10
pH	7.0	7.0	
Turbidity	180.0 J.U.	231.0 J.U.	

*From the above table, it can be seen that wet weather solids content is higher than the dry weather content. This fact does not support opinions that bypassing during rain events constitutes but a minor pollution problem because wastes are weak and diluted. If the above data is typical of storm weather flows from many municipalities, the importance of controlling excess flows, rather than bypassing, becomes more apparent.

Because the demonstration plant was contructed to test the feasibility of operation during storm events, several tests were made to determine the time necessary for start-up. These tests were performed during storm events as well as during dry weather operation.

Starting activities included:

1) Starting the air compressor to build up enough pressure to close the dump valves on the cyclones.
2) Closing the drain valves at the bottom of the air dissolving tank.
3) Closing Gate "A" and opening Gate "C" in the Fort Smith sewage disposal plant distribution box.
4) Starting Pump P-1.

Average time between arrival of operating personnel at the plant site and start-up was 2 minutes. In all tests, Tank 1 was partially filled. If Tank 1 were empty at the start of the tests, one minute additional time would be necessary.

SECTION IX

ADDITIONAL TESTING OF CHEMICAL AIDS TO FLOCCULATION

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ADDITIONAL TESTING OF CHEMICAL AIDS TO FLOCCULATION

Tables 7, 8, and 9 show the results of testing of additional chemical aids to flocculation. The data collected for inclusion in these tables are insufficient for inclusion in Table 5. However, the data are indicative of the ability of these various chemicals to aid the removal of suspended solids and to reduce BOD. In many of the tests included in the following tables, grab samples were used as opposed to the composite samples which were used to compile the data for Table 3. Some rain events occurred during the tests. The data which include percent reduction in BOD are the result of composite sampling.

Chemical feed rates varied widely and are a function of influent waste strength and pH. Reduction of turbidity was initially used as the basis for chemical feed rate adjustment. However, little correlation could be found between turbidity and suspended solids due to the widely varying influent waste characteristics.

Justification for chemical treatment depends largely upon effluent water quality specifications. Data obtained during the demonstration of the dissolved-air flotation unit indicate

TABLE 7

ADDITIONAL CHEMICAL TESTS

Chemical Aids	Suspended Solids % Removal	BOD % Reduction
75 mg/l Alum + 25 mg/l Dow SA1188.1A	97	--
75 mg/l Alum + 50 mg/l Dow SA1188.1A	96	--
75 mg/l Alum + 50 mg/l Dow SA1188.1A	86	76
75 mg/l Alum + 1/4 mg/l Dow A23	73	--
75 mg/l Alum + 1/2 mg/l Dow A23	56	
75 mg/l Alum = 1 mg/l Dow A23	62	--
75 mg/l Alum + 2 mg/l Dow A23	88	--
75 mg/l Alum + 2 1/2 mg/l Dow A23	90	--
75 mg/l Alum + 8 mg/l Drew Floc 400	78	57
60 mg/l Alum + 4 mg/l Drew Floc 410	91	68

TABLE 8

ADDITIONAL CHEMICAL TESTS

Treatment Lime (mg/l)	Drew Floc		Suspended Solids		
	Number	mg/l	Plant Influent mg/l	Plant Effluent mg/l	Removal,%
150		0	260	100	62
150	400	2.5	226	58	74
150	400	1	206	54	74
150	400	5	268*	126	53
150	400	2	242*	126	48
150	410	5	205*	94	54
0	410	5	32	26	19
75	410	5	116	54	53
100	410	5	80	66	18
50	410	5	56	54	4
100	410	1	66	64	3
100	410	2	98	60	39
100	410**	2	200	90	55
100	410**	10	274	88	68
???	410	2	322	78	76
???	410	1	264	70	74

* Blood present in the influent stream.

** Drew Floc injected before air dissolving tank.

??? Measuring equipment inoperative, feed rate unknown, data is included to indicate the potential of the polishing chemical.

Lime was injected immediately before the hydrocyclones except for the two cases marked ??? .

Drew Floc was injected immediately after the air dissolving tank, except as noted.

TABLE 9

ADDITIONAL CHEMICAL TESTS

Alum mg/l	Calgon ST 25* mg/l	Calgon St 266* mg/l	Turbidity Removal,%	Suspended Solids Removal,%
0	40	25	52	61
0	50	25	44	58
0	50	30	50	73
75	0	0	17	48
50	0	10	7	42
75	0	10	-	21
100	0	15	41	42
100	0	20	45	45
125	0	20	72	56
125		25	64	65
	30	20	-	83

* ST 266 is an anionic polyelectrolyte; ST 25 is a clay.

that its effluent waters were often of secondary treatment plant quality when chemical aids were used. The possible savings in equipment and construction costs made possible by a dissolved-air flotation system and chemical aids suggest their consideration as alternatives to secondary treatment.

Costs for various chemical treatments are listed in Table 10. The chemicals are listed alphabetically, and the suggested feed rates are those which gave best removal rates under the influent waste conditions existing during the test. No conclusions have been made. Freight expenses have not been included. Unit costs vary with quantity ordered; the minimum order varies from single 55 gallon drums to 5,000 pound lots.

An average specific gravity of 1.01 for waste water was used in calculating the costs in Table 10. Rates are given in terms of cost per million gallons of waste rather than in cost per pound of dry solids.

Interviews with several filling station operators in the Fort Smith area led to the conclusion that used crankcase oil is often disposed of (illegally) by pouring it into the floor drains in the service station or into nearby storm water catch basins. Several chance observations bore out this fact. In order to determine the effectiveness of the dissolved-air flotation system in removing the oil washed through the combined sewers during the first surge of a rain event, it was necessary to inject oil directly into the flow stream of the demonstration

TABLE 10

CHEMICAL TREATMENT COSTS

Chemical Used And Feed Rate, mg/l	Unit Cost ¢/lb	Removal Total Suspended Solids, %	Cost $ per Million Gallons of Waste
Dry Alum - 75	4	64	25.01
Liquid Alum - 75	1.9	64	11.88
Calgon ST266-20	9.75		
+ Calgon ST25 - 30	50	83	141.30
Dry Alum - 75	4		
+ Dow SA1188.1A - 25	21	97	68.77
Dry Alum - 75	4		
Dow A23 - 2-1/2	31	90	31.47
Dry Alum - 60	4		
Drewfloc 410 - 4	20	91	26.67
Dry Alum - 75	4		
Drewfloc 400 - 8	30	78	45.01
Dry Alum - 30	4		
Anhydrous Ferric Chloride - 30	10		
Tretolite FR-50 - 4	13.7	95	39.58
Anhydrous Ferric Chloride - 56	10	90	46.68
Alum - 75			
Tretolite Fr-50 - 15	13.7	69 to 84	110.66

plant. This was done by using both chemical feed pumps and by pouring oil into the suction stream of pump P-1.

Several tests were performed in which oil was injected into the waste stream or dumped into Tank 1. Little or no oil was visible in the effluent from the air flotation tank. Tests in which analyses were performed confirmed the visual observations. Results are shown in Table II.

TABLE 11

OIL REMOVAL TEST

mg/l Oil Injected into the System	mg/l Oil in the Plant Effluent
Blank	0.6
100	0.6
200	0.6
300	0.6

The oil used for this test was SAE 30 motor oil which had previously been used as a break-in oil for motor vehicles. The oil was injected into an influent waste stream containing slaughterhouse wastes as indicated by the presence of paunch wastes and blood. Table 11 indicates that all the injected oil was removed from the system. It is probable that the oil which was not removed was emulsified or dissolved oil and grease from the slaughterhouse operation. The analytical procedures used for the determination of oil involved use of toluene as an extractant. Colorimetric methods were used to analyze the toluene bearing the extracted oil.

SECTION X

COMPONENT PARTS PERFORMANCE

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COMPONENT PARTS PERFORMANCE

Screen

The initial design of the pilot demonstration plant called for the evaluation of a 3-mesh (1/4 inch) and a 6-mesh (1/8 inch) screen. Removal rates of suspended solids by these screens varied from 6 percent to 49 percent. Removal rates were dependent more upon time elapsed since cleaning of the screen than upon screen size. Solids removal was also a function of the time of the day and waste characteristics. Almost no screenings were collected in the early morning hours. The solids discharge volume increased during the day, reaching a peak in the late afternoon. Frequent manual cleaning, often after 12 to 16 hours of operation, was necessary to prevent total clogging. Clogging was caused by the stapling of fibers and hair over the wires of the screen.

The hair and fiber load was so heavy that addition of plastic cleaning rings recommended by the screen manufacturer proved ineffective. The rate of stapling was so rapid that the cleaning rings became entangled and immovable soon after the cleaned screen was placed in operation.

The manufacturer supplied a 32-mesh screen at his own expense for evaluation to replace the 3- and 6-mesh screens. The 32-mesh screen provided markedly improved solids removal and was in use for one month during which time it was never cleaned. When the screen was removed for return to the manufacturer, it was still clean with no evidence of stapled hair or fibers.

The 32-mesh screen removed between 13 percent and 61 percent of the suspended solids. There are insufficient data to state a statistically significant difference between these removal rates and those for the 3- and 6-mesh screens. However, visual observations indicated that the 32-mesh screen was far superior to the 3- and 6-mesh screens. Also, the 32-mesh screen removed a volume of the solids so great that screenings had to be continuously shoveled from the solids collection box and wheelbarrowed to Fort Smith's grit disposal system.

The removal of this tremendous quantity of solids improved the capacity of Pump P-1 to the point where it was necessary to bypass part of the flow to maintain a flow rate of 350 GPM.

The screen is essential for the treatment of combined sewage; proper mesh size is important. For other applications, the screen may eliminate need for the cyclones.

Cyclones

The demonstration pilot plant was designed with one primary cyclone and three secondary cyclones. Results as indicated in Table 12 show that a flow of 350 gallons per minute, two 10-inch cyclones are sufficient. Cyclones provide maximum efficiency in removing total suspended solids when liquid flow is near capacity. Provision should be made in the design of future systems so that additional cyclones can be readily added if the through-put of the system is increased.

Table 12 lists the pressure differentials across the cyclones for varying flow rates and for several combinations of flow paths through the cyclones.

Cyclone efficiency is a function of pressure differential across the cyclones and optimum pressure differentials indicated by Tables 2 and 12 appear to be in the neighborhood of 20 psi.

All four cyclones were equipped with air-operated dump valves signalled by an electrical impulse coming from a timer. During several storm events, fine clay silt accumulated at such a high rate that solids collection pots on all three secondary cyclones filled and became plugged. The plant had to be shut down and the cyclones dismantled and cleaned. If cyclones are retained they should be designed to permit continuous solids discharge.

TABLE 12

SUPPLEMENTARY DATA ON PRESSURE DROP ACROSS CYCLONES

Flow Thru Plant, GPM	Back Pressure, psi	Pressure Differential Across Cyclones, psi			
		Primary Cyclone	Secondary Cyclones		
			1	2	3
350	50	22	10	10	10
350	40	20	10	10	10
350	30	20	11	9	10
350	20	21	10	7	12
350	50	20	not in use	not in use	not in use
350	50	not in use	20	20	not in use
350	50	not in use	10	10	7
385	50	24	12	9	11
300	50	14	6	6	8
250	50	9	4	2	5
200	50	3	3	0	3
200	50	5	15	not in use	not in use
200	50	not in use	15	not in use	not in use

AIR DISSOLVING TANK

The literature indicates that a liquid retention time of one to three minutes is desirable for dissolving tanks. The air dissolving tank dissolved air by three separate mechanisms:

1) As the air bubbles through the liquid in the inner stand pipe.
2) As the liquid falls through the air cap in the outer stand pipe.
3) In the turbulence produced as the falling liquid strikes the liquid surface at the bottom of the air dissolving tank.

The efficiency of the air dissolving tank was tested by comparing suspended solids removal rates with changes in air pressure in the tank and with changes in air feed rate. A scattergram of the results is shown in Table 13. Values in the body of the table are percent removal rates of suspended solids.

Additional equipment testing was scheduled to determine the proper liquid level in the air dissolving tank. Reference to Figure 5 shows the liquid level controller was located in such a way that liquid level control in the upper half of the sight glass was not possible. The results of the tests were inconclusive; very little difference in the suspended solids removal rate was noticed for all controllable levels of liquid in the air dissolving tank.

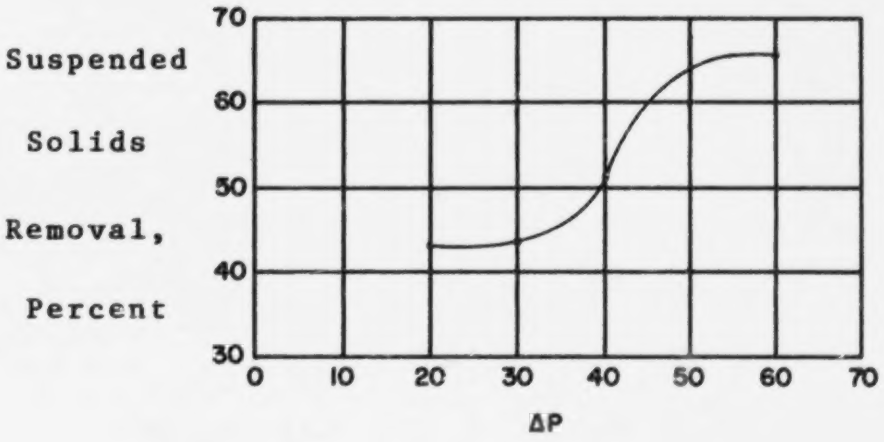
TABLE 13

THE EFFECT OF AIR FEED RATE AND PRESSURE DIFFERENTIAL ON TSS REMOVAL, PERCENT

Pressure psi

Air Feed Rate, cfm	60	50	40	30	20	Mean Values of Suspended Solids Removed
20		64, 43				54
25	73		58	53, 34		54
30	58	62	67, 51, 50, 28		43	51
40		69				69
Mean Values of Suspended Solids Removed	65	54	51	43	43	

The Relationship Between Suspended Solids Removal
Efficiency and Pressure Differential



psi

FIGURE 14

Figure 14 illustrates that suspended solids removal efficiency approaches a maximum in the neighborhood of 50 to 60 psig. Table 13 shows that there is no relationship between air feed rates tested and suspended solids removal rate. This is to be expected, since a surplus air feed rate was designed into the system. Low air feed rates were not tested.

The chemical feed system was arranged so that chemicals could be injected into the waste stream before the cyclones, immediately after the cyclones, or immediately after the air dissolving tank. Various tests were run to determine the optimum point of injecting chemicals. In practically all cases it was determined that best results were obtained when chemicals were injected immediately after the air dissolving tank. Little or no effect was noticed when chemicals were injected before the cyclones.

There were occasions when the feed lines to the chemical feed pumps were clogged. The addition of sight glasses or rotameters in the chemical feed lines to show when chemicals were being pumped might be helpful. Feed pumps capable of handling relatively thick slurries such as might be encountered in the feeding of lime are also desirable.

Two pressure control valves were included in the system (see Figure 7). One valve was automatically operated by a liquid level controller; the other was regulated manually. The automatically operated valve worked very well. It was also relatively easy to maintain pressure in the air dissolving tank using the manually operated pressure control valve. Manually operated valves should be adequate for most applications except in remote or automatic operations.

Air Flotation Cell

Two sets of scrapers were installed in the air flotation cell. The scrapers on the bottom of the cell were used to scrape dense materials deposited on the bottom to a collection channel. The upper scrapers were used to remove the floating foam. Both scrapers were driven by a 1/2 hp variable speed motor which was included in the design to determine the optimum rate of scraper travel. The bottom scraper was activated by a chain drive and fitted with an air-operated clutch and timer to permit intermittent operation. However, when the bottom scraper was not kept in continuous operation, sediment deposited on the bottom of the cell was picked up by turbulence and carried over the exit weir with the effluent stream.

Scraper travel of 6 to 8 feet per minute yielded a foam that was sufficiently thin to flow readily in the foam collection hopper. If other means of removing the foam are used, such as an endless belt or an auger, slower foam scraper speeds can be used.

The amount of water in the foam was dependent upon two factors related to foam scraper speed:

1) The scraper blades extended below the foam into the waste water in the flotation tank. As the blades moved up the foam collection ramp, water was pushed along. At low scraper speeds (4 ft/sec or less), water was able to trickle past imperfections in the blades.
2) At low scraper speeds, the water in the interstices between the foam particles had time to drain away; a dryer foam resulted.

During most of the demonstration, foam consistency was deliberately kept thin to avoid having to wash it from the foam collection trough. The mean total solids content of the foam was 0.43 percent and varied from 0.08 percent to 3.4 percent. During experiments to determine the maximum foam solids concentrations, scraper speeds of 2 to 3 feet per second were used to yield foam consistencies of 5 percent to 7 percent. All foam samples were collected by sampling from Tank 4 with the mixer in operation.

Volatile foam solids varied from 24.7 percent to 83.4 percent, with a mean of 70.3 percent volatility. After standing for several hours, the foam broke and the dense material sank to the bottom of the sample bottle. The less dense material floated. A layer of relatively clear water separated the two fractions. The high volatility of the foam suggests incineration, after dewatering, as a possible method of sludge disposal.

The air flotation cell was 29-1/4 inches deep by 20 feet wide by 15 feet long and was divided into two cells, each 10 feet wide. The exit weir was adjusted to a liquid depth of 19 inches. The inlet nozzles entered the tank 5-3/4 inches from the bottom so the bubble rise was 13-1/4 inches. The effective flotation length of each cell was 12 feet. The remaining length was used for foam collection and effluent liquid collecting troughs (see Figure 8). The theoretical hydraulic retention time of each air flotation cell was 8.2 minutes. Assuming that the 5-3/4-inch layer of liquid below the inlet nozzles is relatively quiescent, the theoretical hydraulic retention time is 5.6 minutes. This agrees closely with the value of 5 minutes indicated with tracer dye tests. The bottom scraper moved counter to the liquid flow and probably set up a circular flow pattern with the hydraulic effect of a still layer. The exit baffle was modified in an attempt to increase the retention time. Modification consisted of moving the exit baffle nearer to the exit weir and extending it to within 2 inches of the bottom of the flotation tank. Although the modification did not noticeably affect the retention time, it did increase efficiency of suspended solids removal approximately 5 percent, apparently by decreasing some hydraulic short-circuiting in the tank.

Valves installed in the inlet leaders were adjusted to direct all flow through one cell in an attempt to determine the optimum flotation cell flow rate. The pumping rates were varied from 125 GPM to 380 GPM. Design through-put per cell was 175 GPM. Pressure differential and air feed rates were held constant at 50 psig and 30 cfm, respectively; no chemicals were used. Results of this test shown in Table 14 lead to the conclusion that the flotation tank had greater capacity than the design value; there was little or no difference between the rates of suspended solids removal for the flow rates used.

TABLE 14

THE EFFECT OF FLOW RATE ON SUSPENDED SOLIDS REMOVAL

Pumping Rate GPM	Effective Flotation Tank Throughput Rate GPM	Suspended Solids Removal %
350-380	700-760	60
200-225	400-450	65
175 *	350	62
150	300	61
125	250	66

* Design Flow Rate

To determine the minimum depth of the flotation tank, a series of holes were cut in the exit weir of one cell of the flotation tank. The location and size of the holes is indicated in Figure 15.

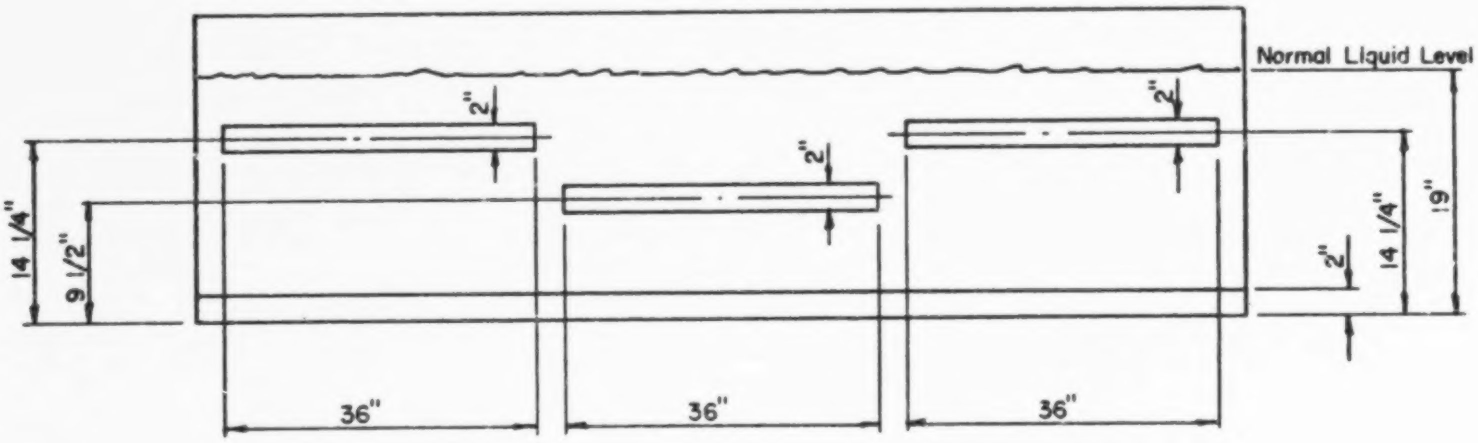

Normal Liquid Level
2"
2"
2"
2"
14 1/4"
9 1/2"
14 1/4"
19"
36"
36"
36"

FIGURE 15

The lower holes were covered and sealed in order to test the effect of lowering the liquid depth to 14-1/4 inches (three-quarters of the designed depth of 19 inches). The lower set of holes was used to test the efficiency of suspended solids removal at one-half design depth. The results shown in Table 15 show a sharp drop in efficiency for the shallower cells and fix the minimum depth in the neighborhood of 19 inches. A simultaneous test was performed using the unmodified cell for comparison purposes.

TABLE 15

EFFECTIVE FLOTATION DEPTH

Liquid Depth, in.	Distance of Bubble Rise, in.	Suspended Solids Removal,%
19(unmodified cell)	13.25	92.1
14.25	8.5	73.0
9.5	3.75	71.3

To aid in suspended solids removal in this test, 100 mg/l alum and 20 mg/l Tretolite FR-50 were used as flocculating aids. The tests were performed during a period when there was little variation in the influent waste stream; influent pH was 7.1 and the influent suspended solids content was 784 mg/l.

SECTION XI

BENEFIT-COST RELATIONSHIPS

BENEFIT-COST RELATIONSHIPS

A hypothetical community was considered in order to obtain an analysis and comparison of costs and benefit-cost ratios. 75 rain events, averaging 4 hours each occur annually in this community. Run-off disposal is by means of combined sewers which overflow directly into a nearby river. The suspended solids content of the overflow averages 534 mg/l, which was the average value at Fort Smith.

It was assumed that the city needed to provide primary treatment of the overflow to comply with effluent waste water quality standards. Conventional clarifiers and dissolved air flotation were chosen for comparison. The costs and benefits of each method are presented in Table 16 for flow rates varying from 1 MGD to 20 MGD.

To aid in the analysis, it has been assumed that an overflow outfall already exists above the high water line of the river, so the cost of delivering the waste overflow to the treatment plant need not be considered. Land is available at $100 per acre. Twenty-year, 5.5 percent bonds will be used for financing. The expected life of both treatment plants is 50 years.

Evans, et al., (35) in their study of the treatment of urban storm water run-off suggest that during storm events, conventional clarifiers with four hours retention time can

TABLE 16

COSTS AND BENEFITS, AIR FLOTATION AND CONVENTIONAL CLARIFIERS

Capacity MGD	Treatment	Total Installed Cost Including Land	Total Interest @ 5.5% 20 yrs.	Annual Amortized Cost	Annual Operating & Maintenance Costs	Total Annual Cost	Lb Suspended Solids Removed Annually	Benefit Cost Ratios *
1	Air Flotation	$26,380	$29,020	$2,770	$2,990	$5,760	38,920	6.8
	Conv. Clarifier	44,520	48,960	4,675	1,500	6,175		6.3
2	Air Flotation	43,270	47,600	4,545	3,970	8,515	77,840	9.1
	Conv. Clarifier	69,435	76,380	7,290	1,770	9,060		8.6
4	Air Flotation	73,085	80,400	7,675	5,720	13,395	155,690	11.6
	Conv. Clarifier	108,225	119,160	11,370	2,140	13,510		11.5
8	Air Flotation	123,440	135,800	12,960	8,750	21,710	311,380	14.3
	Conv. Clarifier	168,950	185,900	17,745	2,750	20,495		15.2
16	Air Flotation	208,495	229,420	21,895	14,890	36,785	622,750	16.9
	Conv. Clarifier	263,550	290,020	27,680	4,600	32,280		19.3
20	Air Flotation	253,135	278,460	26,580	17,600	44,180	778,440	17.6
	Conv. Clarifier	308,465	339,320	32,390	5,050	37,440		20.8

* Lb suspended solids removed/$.

remove 70 percent of the suspended solids. These values were used as a basis for the design of the clarifiers, since the removal rates approximate those attained during storm events using dissolved-air flotation at Fort Smith.

The bases for calculating operating and maintenance costs are:

1) Electricity @ 1¢/hr/H.P.

Capacity MGD	Horsepower Flotation Units	Conventional Clarifiers
1	50	1
2	95	1
4	180	1
8	350	2
16	680	4
20	840	4

2) Labor costs are the same for both air flotation units and conventional clarifiers of equal capacity at the rate of 4 hours per rain event for the 1-, 2-, 4-, and 8-MGD plants and 8 hours per rain event for the larger plants. Cleanup activities are responsible for most of the labor charges.

3) Maintenance

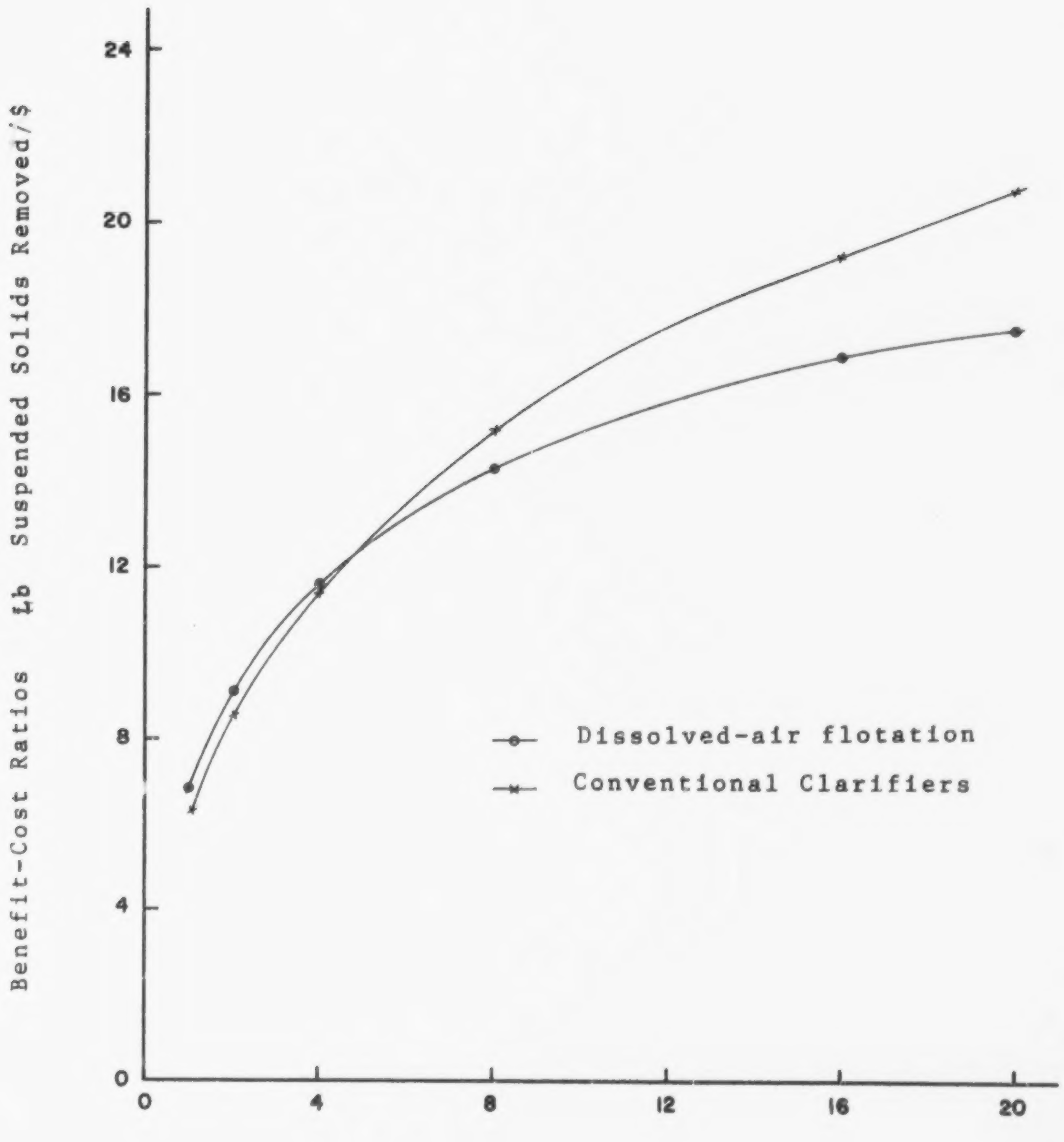
	Air Flotation	Conventional Clarifiers
Labor	4 hours per week @ $3.00 per hour	1 hour per week @ $3.00 per hour
Parts and Supplies	5% of initial cost	1% of initial cost

Cost analyses are provided for the installed clarifiers and flotation units only and do not include the costs of treating the separated solids and sludge or the effluent waste waters. These cost factors must be included in any comprehensive cost analysis (36).

Table 17 shows that only 0.1 as much land area is needed by dissolved-air flotation units. This could be important at overflow points.

The benefit-cost ratios in pounds of suspended solids removed per dollar of annual cost, shown in Table 16, favor dissolved-air flotation for capacities less than 8 MGD. Figure 16 illustrates the data of Table 16 in graphical form.

If dissolved-air flotation is used for treatment, additional savings are realized because the floated foam has a solids content of 7 percent and a thickener will probably be unnecessary. Flotation cell underflow, containing solids which sink to the bottom, can be controlled to yield a low volume sludge of 1 to 2 percent consistency. Mixing the solid screenings with the underflow will increase the solids content of the foam-underflow mixture. This sludge should be amenable to



Capacity, MGD

FIGURE 16

TABLE 17
PHYSICAL SIZES AND LAND AREAS REQUIRED BY CONVENTIONAL CLARIFIERS AND DISSOLVED AIR FLOTATION UNITS

	Conventional Clarifiers				Air Flotation			
	Tank Size				Cell Size			
Capacity MGD	Diameter ft	Depth ft	Number Required	Area Needed sq ft	Length	Width	Number of Cells	Area Required sq ft
1	50	11	1	3600	12	10	2	350
2	70	11	1	6400	12	10	4 *	350
4	100	11	1	12100	12	10	8 *	700
8	140	11	1	22500	12	40	4 *	2000
16	200	12	1	44100	12	40	8 *	4000
20	150	11	2	50400	12	40	10 *	5000

* Cells can be stacked two high to conserve space.

direct vacuum filtration with an expected filter cake moisture content of 70 percent (36). Final disposition of the filter cake is dependent upon local conditions. Some typical options include:

1) Incineration.
    a. On site.
    b. Trucking to off-site incinerator.
2) Burial.
3) Composting.

Alternatives to dewatering the sludge on site include digestion on site and pumping to an existing treatment plant for treatment. On-site digestion appears to present more problems and is the less attractive.

SECTION XII

POSSIBILITIES FOR AUTOMATION
AND
OTHER POTENTIAL APPLICATIONS

POSSIBILITIES FOR AUTOMATION
AND
OTHER POTENTIAL APPLICATIONS

Automation Possibilities

Results of the tests performed and observations obtained at the plant site indicate that the operation might well be automated. In very few instances was the operator necessary. With the use of standard, easily available equipment, the entire operation could be automated from start-up to shut-down. An automated unit would also be adaptable for use at remote locations.

Detailed design of an automated unit is somewhat dependent upon conditions and location. However, the basic premises will remain fairly constant. The modification of the existing Fort Smith plant will be used as an example in the discussion of the design of an automated dissolved-air flotation system.

The design includes a method of disposing of the foam and the solid wastes from the screen, the cyclones, and the bottom of the flotation cell. Some of the design modifications recommended earlier in this report have been included in this design.

The following items are considered essential for the modification. Figure 17 is a detailed diagram of this design.

1) Select start up mechanism. The criteria is the detection of increased flow to the Fort Smith municipal treating plant.

   a. A liquid level sensor set at a predetermined level in the 12 ft concrete "P" Street interceptor will detect rising water and will signal the start of a sequential start-up, washing, and shut-down cycle.

   b. Manual start of the sequence. (For check out of the unit.)

2) Revise the existing flow rate measurement and control system.

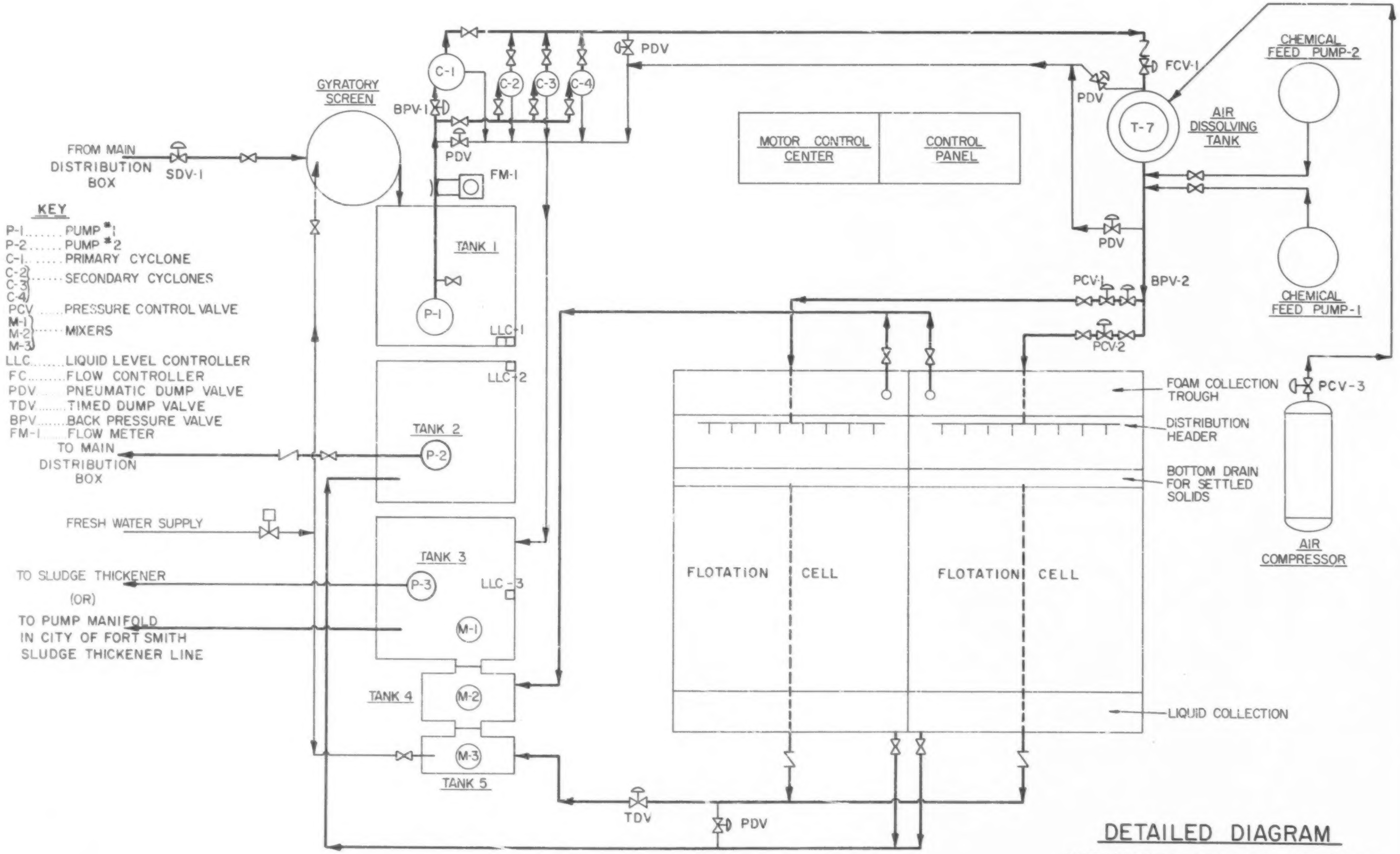
   a. A flow controller signaled by the existing orifice-flow recorder system will:

      1. Actuate a pneumatic flow control valve (FCV-1) upstream of the air dissolving tank.

      2. Regulate air flow to the air dissolving tank (T-7) by means of a pressure control valve (PCV-3).

      3. Open and close a by pass valve (BPV-1) controlling flow to the primary hydrocyclone (C-1).

   b. Control of the by pass valve (BPV-1) may be provided through the use of signals from a liquid level controller (LLC-1) in the liquid to influent Tank 1.


FROM MAIN DISTRIBUTION BOX
SDV-1
GYRATORY SCREEN
BPV-1
C-1
C-2
C-3
C-4
PDV
FM-1
TANK 1
P-1
LLC-1
LLC-2
TANK 2
P-2
TANK 3
P-3
LLC-3
M-1
TANK 4
M-2
TANK 5
M-3
TDV
MOTOR CONTROL CENTER
CONTROL PANEL
FCV-1
T-7
AIR DISSOLVING TANK
CHEMICAL FEED PUMP-2
CHEMICAL FEED PUMP-1
BPV-2
PCV-1
PCV-2
PCV-3
AIR COMPRESSOR
FOAM COLLECTION TROUGH
DISTRIBUTION HEADER
BOTTOM DRAIN FOR SETTLED SOLIDS
LIQUID COLLECTION
FLOTATION CELL
FLOTATION CELL
KEY
P-1.......PUMP #1
P-2.......PUMP #2
C-1.......PRIMARY CYCLONE
C-2, C-3, C-4.......SECONDARY CYCLONES
PCV.......PRESSURE CONTROL VALVE
M-1, M-2, M-3.......MIXERS
LLC.......LIQUID LEVEL CONTROLLER
FC.......FLOW CONTROLLER
PDV.......PNEUMATIC DUMP VALVE
TDV.......TIMED DUMP VALVE
BPV.......BACK PRESSURE VALVE
FM-1.......FLOW METER
TO MAIN DISTRIBUTION BOX
FRESH WATER SUPPLY
TO SLUDGE THICKENER
(OR)
TO PUMP MANIFOLD
IN CITY OF FORT SMITH
SLUDGE THICKENER LINE

DETAILED DIAGRAM
AUTOMATED STANDBY COMBINED
STORMWATER-DOMESTIC SEWAGE
TREATMENT PLANT

(FIGURE 17)

3) Design a sequential turn-on, turn-off, clean-up, and shut-down cycle.

   a. An electric signal will start the air compressor and energize all electrical control circuits.

   b. Air will open shut-down valve (SDV-1) and start the screen.

   c. Air will close all dump valves.

   d. A rising liquid level in Tank 1 will close a pump switch to:

      1. Start Pump P-1.
      2. Start the foam and bottom scrapers.
      3. Start Chemical Feed Pump 1.

   e. A high-low liquid level safety shut-down will control SDV-1 and prevent overflow of Tank 1.

   f. The flow rate will be controlled by a signal from a flow controller connected to the orifice 3 pen recorder system (FM-1), from liquid level controller (LLC-1), or from both. The signals will:

      1. Provide throttling through flow control valve (FCV-1).
      2. Control flow through the primary cyclone by opening by pass valve (BPV-1) when flow rates exceed 350 GPM.
      3. Control flow to one flotation cell by opening by pass valve (BPV-2) when flow rates exceed 350 GPM.

4. Regulate air flow to the air dissolving tank (T-7) by means of the pneumatically operated pressure control valve (PCV-3). Start Feed Pump-2.

g. An air operated valve signaled by a timer on the chain drive turning the bottom scrapers will permit periodic dumping of the bottom sludge in the flotation cells.

h. A liquid level controller (LLC-2) will stop the liquid effluent pump (P-2) in the liquid effluent Tank 2.

i. Fort Smith Sewage Department personnel pump the sludge hoppers to the existing clarifiers every 2 hours. Volumes of sludge and foam accumulated in 2 hours are not expected to exceed the capacity of the storage facilities (Tanks 3, 4 and 5). Mixers will be controlled by liquid level controllers.

j. When the liquid level in the 12 ft concrete interceptor falls below the predetermined height or at the discretion of the Superintendent of the Fort Smith Sewage Disposal Facility, the clean-up and shut-down sequence will begin.

k. The shut-down valve (SDV-1) will close.

l. The pump switch will stop Pump P-1 when the liquid level falls in the liquid influent Tank 1.

An override switch will keep the screen and scrapers in operation.

m. A signal will trigger an air operated valve, dumping fresh rinse water through the screen into Tank 1.

n. Pump P-1 will start, flushing the system with rinse water.

o. A timer will close the fresh water valve and stop the screen. Pump P-1 will stop at the low level signal.

p. The air compressor and scrapers will stop.

q. Dump valves will drain all lines and the flotation cells to the liquid effluent Tank 1. When Tank 2 is empty a timer will turn off power to the electrical control circuits and reset the air compressor switch to repeat the sequence on signal.

r. An electrical lockout will prevent SDV-1 from opening when the wash-out cycle is in operation.

4) Replace the 3- and 6-mesh screens with screens of 32 mesh or smaller. During these tests, the 32-mesh screen exhibited little or no tendency to blind because of stapling.

5) Change the solids discharge system on the hydrocyclones to continuous blowdown. The use of smaller screens will permit the removal of the automatic dump valves and the solids pots on the hydrocyclones

and the installation of apex valves with small diameters. This will permit continuous blowdown of solids with a bypass of approximately 3 percent of the liquid flow.

6) Modify the hydrocyclone flow sequence.

   To accommodate a flow rate of 700 GPM, the primary cyclone (C-1) will be placed in parallel with the bank of secondary cyclones (C-2, C-3, C-4). C-1 will be cut out of the circuit at flow rates of 350 GPM or less.

7) Select a discharge system for the flotation cell liquid effluents.

   The present demonstration plant remixes all the solid and liquid effluents. Modification of the discharge system will permit the discharge of the separated solids and liquids. The existing liquid effluent pump (P-2) will be moved to the liquid effluent Tank 2. Liquid effluent from the flotation cells will be pumped to the exit cell of the Fort Smith distribution box, decreasing the hydraulic load in the Fort Smith sewage disposal plant and increasing the efficiency of solids removal during storm events.

8) Select a disposal system for the solids collected.

   a. A gravity flow line will run from mixing Tank 3 to an existing line upstream of the Fort Smith sludge pump.

   b. A stop valve would prevent back flow.

c. A pump (P-3) installed in mixing Tank 3 will pump the accumulated sludge and foam to the Fort Smith sludge thickeners. The solids removed by the screens, cyclones, and flotation cells would not pass through the Fort Smith clarifiers. The automated unit thereby will decrease the solids load and further increase the efficiency of the Fort Smith sewage disposal plant.

9) Redesign the sludge collection trough on the bottom of each flotation cell.
The slotted pipe in the collection trough will be removed and replaced with an inclined plane to improve the bottom sludge collection efficiency, provide for a more positive hydraulic sweeping action, and minimize channeling.

10) Design a spray jet system to wash the chains and sprockets during the clean-up cycle.

Other Potential Applications

Combined sewer and storm water overflows are not the only source of pollution in the nation's receiving waters. The research project discussed in this report has suggested answers to industrial waste pollution problems as well. Some of these are discussed below.

One application includes use by the meat processing industry. Fort Smith sewage contained quantities of feathers, hair, paunch wastes, and blood. These materials were easily removed by the plant. Most of the blood was removed, and a very clear liquid effluent was obtained. However, it was difficult to remove all of the color.

Some present applications of the dissolved-air flotation system were discussed in Section IV. Similar systems have been used in the petroleum industry, and the design discussed in this report seems particularly adaptable to oil field applications. Low retention time plus extreme compactness make dissolved-air flotation very suitable for use on offshore production platforms.

Dissolved-air flotation systems are currently being used by several of the food processing industries. Some canneries use the air flotation system to remove suspended solids from their process wastes. In most cases, the air flotation cells being used are of the old design in which retention times are approximately one hour or longer. The design demonstrated at Fort Smith is unique in that:

1) Air is dissolved in the entire waste flow, and
2) The retention time in the air flotation tank is extremely short.

Future plants might well be designed around a basic unit with dimensions the same as a single cell of the air flotation tank located at Fort Smith; approximately 10 feet wide with an effective inner length of 12 feet. An entire plant (0.5 MGD) could be contained on a skid, trailer, or pad with dimensions of 10 feet by 25 feet. If additional hydraulic capacity is necessary, tanks could be paralleled or stacked one above another. The area of the pad not occupied by the air flotation tank would be used for the ancillary equipment.

The same concept is sound for larger or smaller flotation cell dimensions and capacities.

Recommendations for future development of dissolved-air flotation include:

1) Further investigation using specific industrial wastes from the ferrous and nonferrous metal industries, packing houses, rendering plants and slaughterhouses, and the petrochemical and petroleum industries.
2) Design and construction of a completely automatic, in-line plant to be used in one or more of the above applications.
3) The construction and operation of a pilot plant in which the specific goal would be to test various

chemical aids to flocculation both singly and in combination, attempting to reduce suspended solids, BOD, total phosphates, and total nitrogen.

4) Use of the dissolved-air flotation system as the primary treatment device in combination with various high rate secondary devices to produce a very high quality effluent waste water. Suggested secondary devices include high rate trickling filters or a rapid sand filter (to remove the remaining suspended materials) followed by an activated carbon unit (to remove BOD and dissolved chemicals). This step, in turn, could be followed by chlorination or aeration or both.

5) Use of the dissolved-air flotation unit with chemical aids as a replacement for both primary and secondary treatment plants.

SECTION XIII

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SECTION XIV

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SECTION XV

APPENDICES

A. Photographs of the Demonstration Plant

B. The Fort Smith Drainage Area

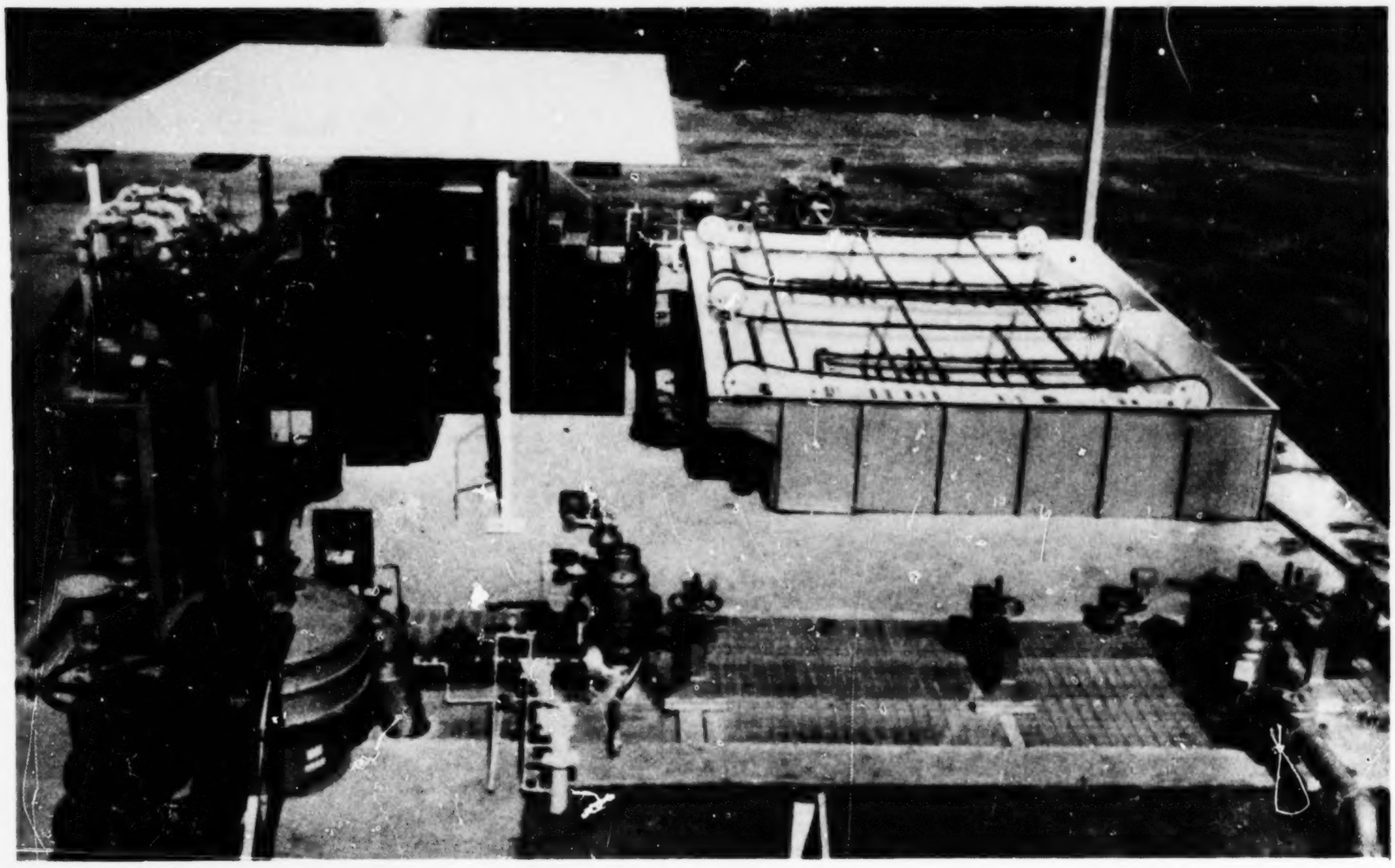
C. Construction Costs

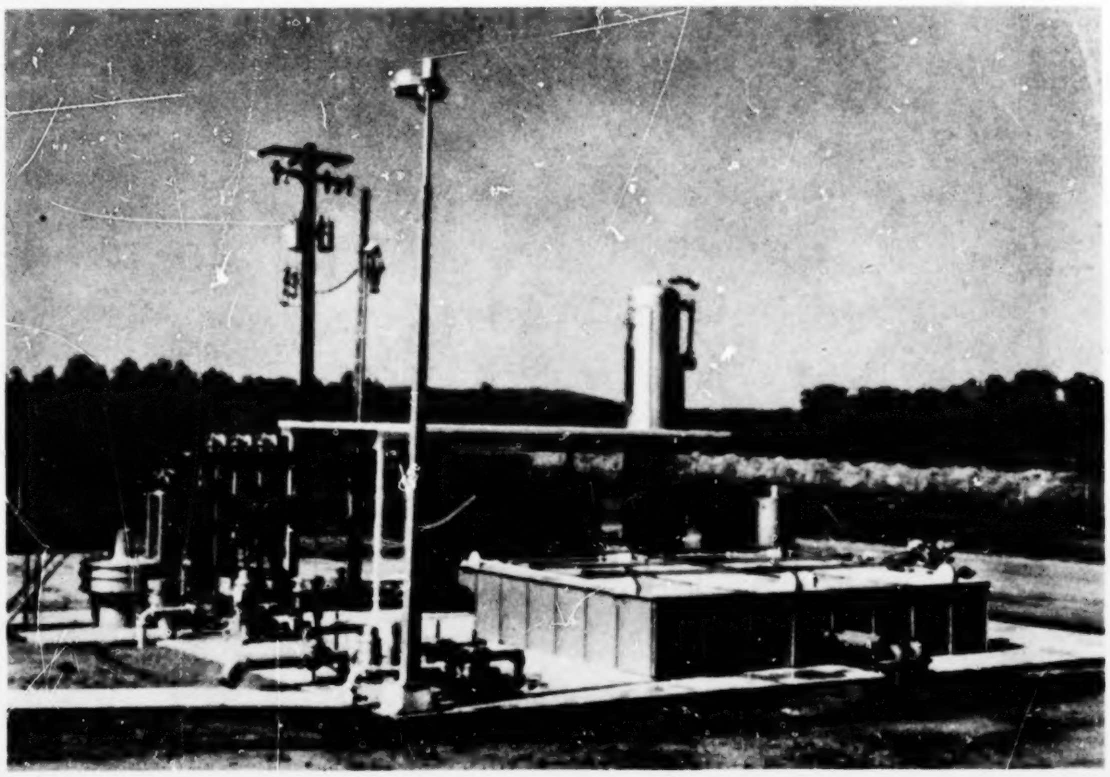
D. Data and Calculations

E. Typical Data Obtained During Plant Shake Down in 1967

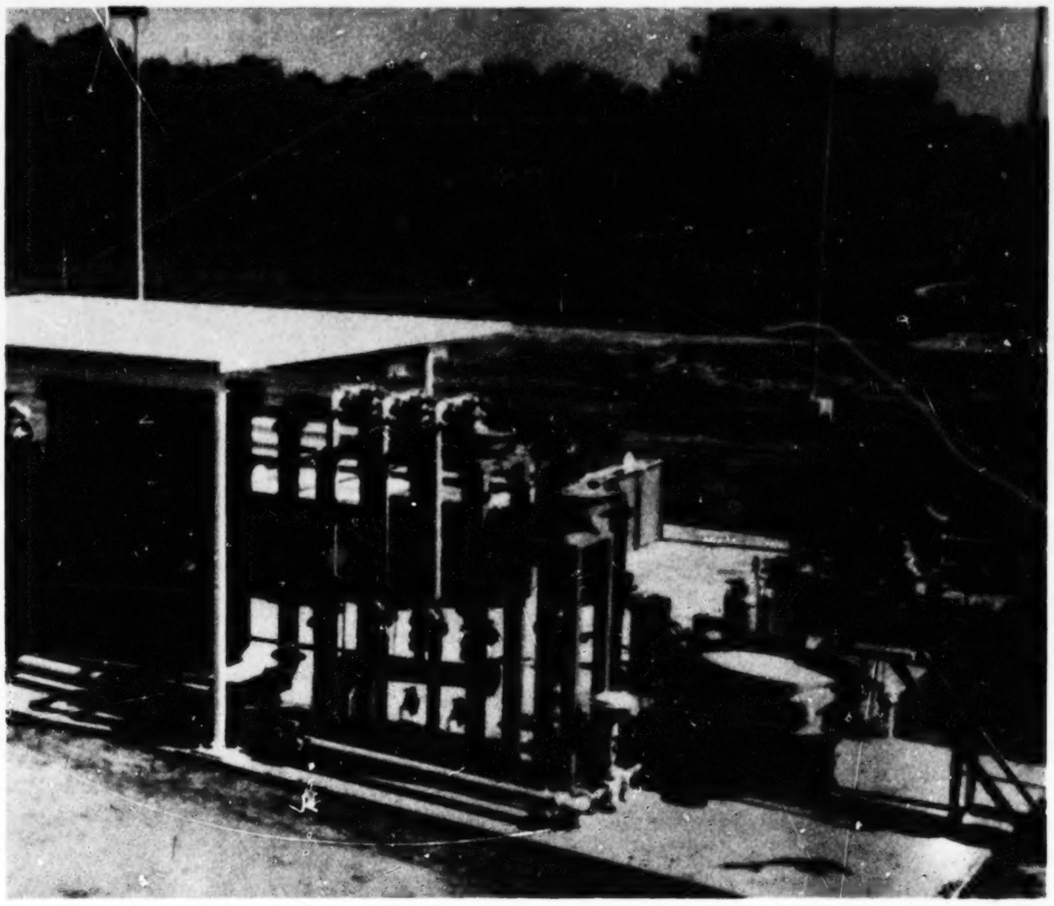
APPENDIX A

PHOTOGRAPHS OF THE DEMONSTRATION PLANT

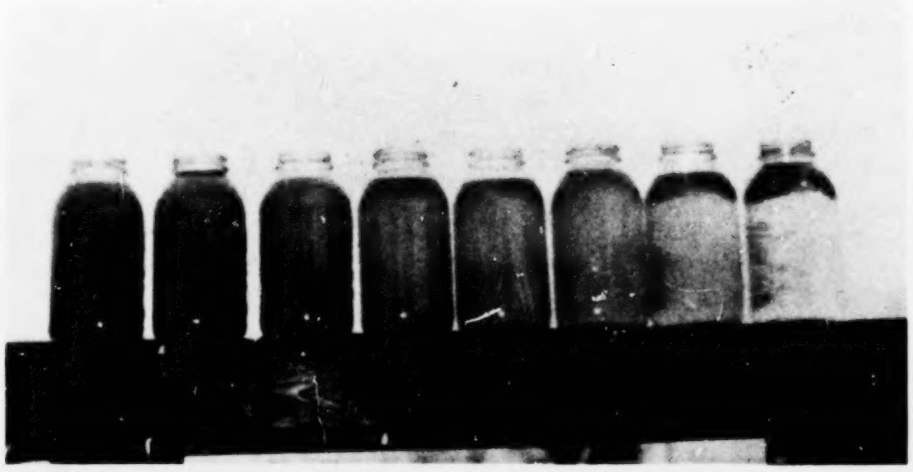




Two views of the demonstration pilot plant showing the major pieces of equipment. The visqueen cover has been removed from the air-flotation tank.



A view of the four hydrocyclones used in the demonstration pilot plant.



Comparison of different treatments. The first jar on the left contains untreated influent waste; the remaining jars contain plant effluents, reading left to right, no chemical treatment, 50 mg/l Alum, 75 mg/l Alum, 100 mg/l Alum, 125 mg/l Alum, 125 mg/l Alum + 15 mg/l Tretolite FR-50, and tap water. A heavy load of blood was present in the influent stream.

APPENDIX B

THE FORT SMITH DRAINAGE AREA

The Fort Smith drainage area is approximately 12,000 acres. About 10 percent of this total has water-impervious covers such as streets, parking lots, houses, etc. The city proper covers an estimated three-fourths of the area.

The 1960 U. S. Census listed the Fort Smith population as 52,991; the 1962 population was 63,309; and the 1968 population of Fort Smith has been estimated in the neighborhood of 70,000. The Fort Smith sewer department had an average of 16,300 non-industrial customers in 1968 and 222 industrial customers. Three major industries dispose of their wastes directly to the Arkansas River.

Of the nine million gallons of potable water produced per day, about 70 percent is used for domestic and residential purposes. The total daily waste volume of 5.3 million gallons is treated in two plants - North "P" Street, the location of the demonstration plant,and Massard Creek. The Massard Creek facility provides both primary and secondary treatment for 1.8 million gallons per day of waste estimated to be of 95 percent domestic origin. The Massard Creek treatment plant was built as the result of an engineering study submitted to the City of Fort Smith in 1962. The plant has a daily capacity of ten million gallons to provide for future expansion of the city in the Massard Creek area. The plant's current flow is sufficient to operate only one of the two trickling filters. There are no sludge treatment facilities other than a vacuum filter; filter solids are buried.

The North "P" Street treatment plant consists of bar screens, primary clarifiers, degritters, sludge thickeners and vacuum filters. Total daily waste flow averages 3.5 million gallons which is estimated at 77 percent industrial waste. The clarifiers have a retention time of one hour and forty-five minutes and have a design surface loading rate of 700 gallons per square foot per day.

The sewage collection system in the city consisted of 170 miles of combined and separate sewers as of January 1, 1969. At that time, there were seven pump stations in operation with five more in various stages of construction. Upon completion of these pumping stations, there will be two sewage outfalls for the city, one for each of the treatment plants.

As of January 1, 1969, the City of Fort Smith had no municipal restrictions or regulations pertaining to sewer connections or sewage discharge rates and strengths. The State of Arkansas Water Pollution Control Regulations are being used in lieu of city laws.

The Fort Smith drainage area is described in Table B-1, and a map of this area is shown in Figure B-1.

TABLE B-1

THE FORT SMITH DRAINAGE AREA

The area covers about 36 square miles and includes:

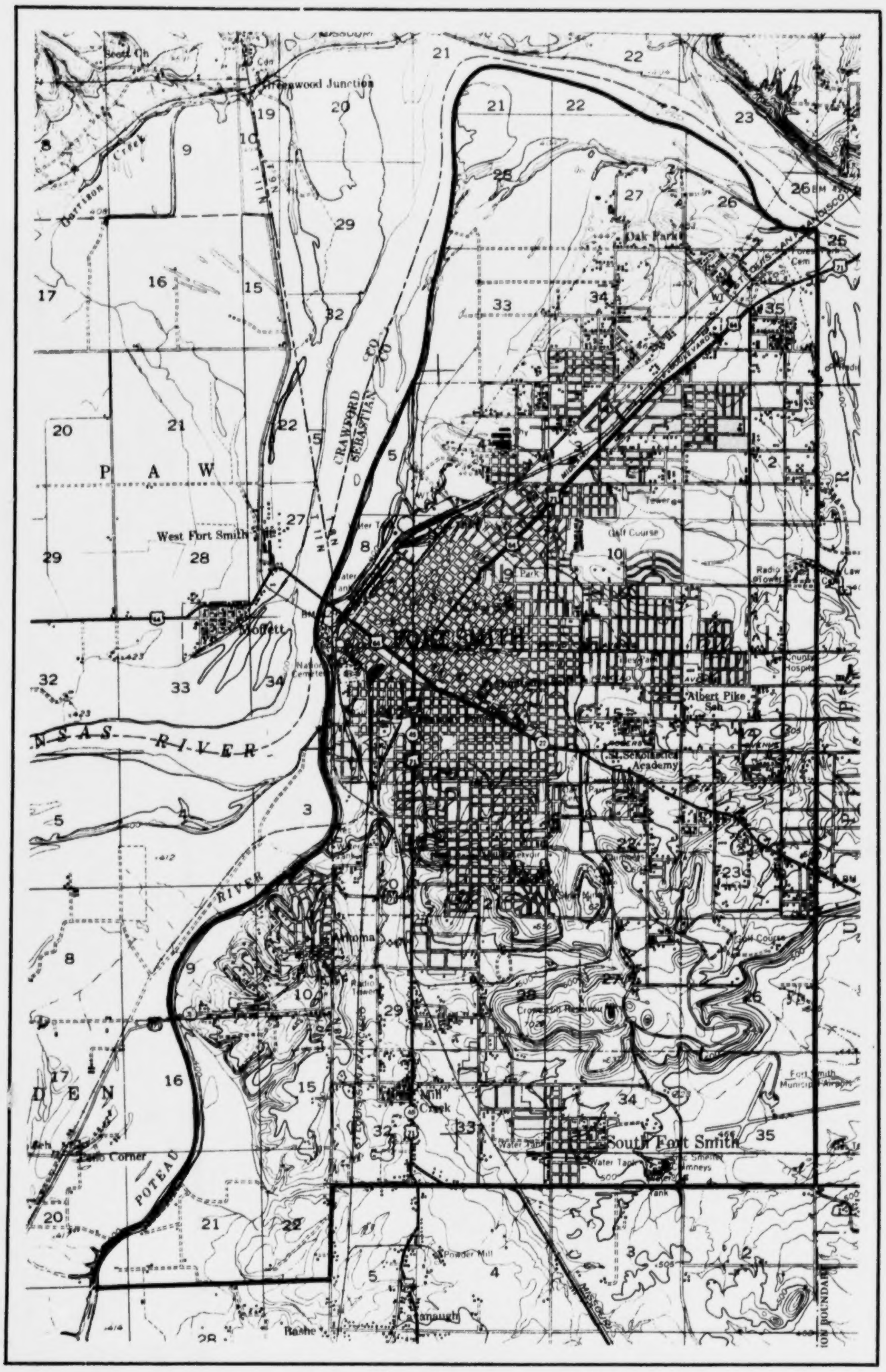
T 10 N, R 27 E, Sections 9*, 10, 15, 16*, 21*, 22

T 11 N, R 27 E, Sections 34* in the State of Oklahoma, and;

T 8 N, R 32 W, Sections 2, 3, 4, 5*, 8*, 9, 10, 11, 14, 15, 16, 17, 20, 21, 22, 23, 26, 27, 28, 29, 32, 33, 34, 35

T 9 N, R 32 W, Sections 21*, 22*, 26, 27, 28, 33, 34, 35 in the State of Arkansas.

*Part of the section.


Greenwood Junction
West Fort Smith
Moffett
FORT SMITH
Golf Course
Albert Pike Sch
St. Scholastica Academy
Arkoma
South Fort Smith
Fort Smith Municipal Airport
Oak Park
Garrison Creek
CRAWFORD
SEBASTIAN
POTEAU
RIVER
Pano Corner
Cavanaugh
Powder Mill
0 1/2 0 1 Mile
SCALE: MILES
C.I.= 20 FT.

THE FORT SMITH DRAINAGE AREA

FIGURE B-1

APPENDIX C

CONSTRUCTION COSTS

CONSTRUCTION COST RESUME
FOR THE
DISSOLVED AIR FLOTATION DEMONSTRATION PILOT PLANT AT FT. SMITH, ARKANSAS

I CONSTRUCTION

Subcontractor's Fee:			
Section I	Civil Work		$ 6,800.00
Section II	Mechanical Work		8,400.00
Section III	Electrical Work		4,500.00
	SUBTOTAL:	$ 19,700.00	
Material Furnished by Rhodes			
Concrete, Gravel, Sand			908.38
Reinforcement Steel,etc.			951.87
	SUBTOTAL:	$ 1,860.25	
	I - TOTAL	$ 21,560.25	

II MECHANICAL EQUIPMENT

(1) Flotation Cell	9,955.55
(1) Air Dissolving Tank	2,948.00
(1) Screen	3,673.00
(4) Cyclones	4,068.50
(1) Electric Control Panel	2,401.90
(1) Motor Control Center	3,794.00
(2) Sewage Pumps	2,371.70
(2) Chemical Feed Pumps w/100 gal. tank	1,408.00
(1) Air Compressor	1,351.00
(5) Mixers	1,900.00
(7) Liquid Level Controllers	1,175.00
(1) 3-Pen Recorder	453.70
(1) Instrument Air Dryer	107.85
(1) Flow Meter w/40" open flow nozzle	814.50
(1) Air Flow Meter	99.25

II Mechanical Equipment (Continued)--

(4)	Slide Gates	$ 2,210.00
(9)	Air Regulators	135.00
(1)	Liquid Level Gauge	142.02
(2)	Temperature Indicators	1,046.00
(24)	Pressure Indicators	1,072.77
(4)	Pressure Controllers	357.85
	Electric Supply Material	1,856.15
(1)	Flow Tube	343.20
(2)	Flow Controller	102.00
(106)	Valves	7,062.85
	Pipe Fittings	1,736.13

II TOTAL $ 51,585.79

GRAND TOTAL $ 73,146.04

APPENDIX D

DATA AND CALCULATIONS

Influent pH During Dry Weather

pH	f
3.2	1
6.2	1
6.4	2
6.5	4
6.6	7
6.7	5
6.8	12
6.9	5
7.0	26
7.1	18
7.2	10
7.3	11
7.4	3
7.5	2
7.8	1
8.3	1
8.7	1
TOTAL	110

$\bar{X} = 7.0$

$S = 0.3$

Median = 7.0

95% Confidence Interval

$6.9 \leq \mu \leq 7.1$

$\bar{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent Turbidity During Dry Weather

Turbidity Jackson Units	f
500 - 549	1
450 - 499	1
400 - 449	1
350 - 399	3
300 - 349	7
250 - 299	6
200 - 249	26
150 - 199	17
100 - 149	33
50 - 99	10
0 - 49	8
TOTAL	113

$\overline{X}$ = 180 J.U.

S = 99 J.U.

Median = 177 J.U.

95% Confidence Interval (37)

$178 \leq \mu \leq 182$

$\overline{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent Suspended Solids and Volatile Suspended Solids Concentrations During Dry Weather

Suspended Solids mg/l	f
900-999	3
800-899	1
700-799	3
600-699	2
500-599	4
400-499	2
300-399	20
200-299	34
100-199	25
TOTAL	112

$\overline{X}$ = 272.3 mg/l

S = 201 mg/l

Median = 239 mg/l

95% Confidence Interval

$269.7 \le \mu \le 274.9$

Volatile mg/l	Suspended Solids f
350	2
325	3
300	0
275	1
250	8
225	11
200	5
175	9
150	4
125	2
100	0
75	4
TOTAL	49

$\overline{X}$ = 195.1 mg/l

S = 14.5 mg/l

Median = 202 mg/l

95% Confidence Interval

$194.0 \le \mu \le 196.2$

The table does not include suspended solids for two isolated events during which the concentrations were 1297 mg/l and 1140 mg/l.

Influent BOD Concentrations During Dry Weather

BOD mg/l	f
320 - 339	1
300 - 319	2
280 - 299	4
260 - 279	4
240 - 259	6
220 - 239	5
200 - 219	3
180 - 199	10
160 - 179	9
140 - 159	11
120 - 139	7
100 - 119	1
80 - 99	3
60 - 79	2
40 - 59	3
20 - 39	4
0 - 19	1
TOTAL	76

$\bar{X}$ = 174.5 mg/l

S = 75.8 mg/l

Median = 174 mg/l

95% Confidence Interval

$168.3 \leq \mu \leq 180.7$

$\bar{X}$ = Sample Arithmetic Mean
S = Standard Deviation
μ = True Population Arithmetic Mean

Influent Total Solids and Total Volatile Solids Concentrations During Dry Weather

Total Solids	
mg/l	F
900-999	5
800-899	8
700-799	8
600-699	17
500-599	17
400-499	8
300-399	1
200-299	2
100-199	3
TOTAL	69

$\overline{X}$ = 621.0 mg/l
S = 189.5 mg/l
Median = 623 mg/l
95% Confidence Interval
$617.8 \le \mu \le 624.2$

Total Volatile Solids	
mg/l	F
601-650	1
551-600	1
501-550	1
451-500	1
401-450	5
351-400	10
301-350	11
251-300	7
201-250	7
151-200	3
TOTAL	47

$\overline{X}$ = 348.9
S = 18.8
Median = 340
95% Confidence Interval
$347.7 \le \mu \le 350.1$

The table does not include total solids for several isoladed events in which concentrations were as high as 2136 mg/l.

$\overline{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Total Influent Phosphate Concentration During Dry Weather

Total Phosphate mg/l	f
80 - 89	2
70 - 79	2
60 - 69	11
50 - 59	13
40 - 49	9
30 - 39	15
20 - 29	21
10 - 19	6
0 - 9	2
TOTAL	81

$\bar{X}$ = 39.8 mg/l

S = 25.5 mg/l

Median = 38 mg/l

95% Confidence Interval

$38.7 \leq \mu \leq 40.9$

$\bar{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent Total Nitrogen During Dry Weather

Total Nitrogen mg/l	f
30.0 - 31.9	1
28.0 - 29.9	0
26.0 - 27.9	2
24.0 - 25.9	2
22.0 - 23.9	6
20.0 - 21.9	22
18.0 - 19.9	20
16.0 - 17.9	9
14.0 - 15.9	2
12.0 - 13.9	8
10.0 - 11.9	4
8.0 - 9.9	4
6.0 - 7.9	2
4.0 - 5.9	2
TOTAL	84

$\bar{X}$ = 17.7 mg/l

S = 5.0 mg/l

Median = 19.3 mg/l

95% Confidence Interval

$17.2 \leq \mu \leq 18.2$

$\bar{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent pH During Storm Events

	pH
	7.4
	7.3
	7.3
	7.3
	7.2
	7.2
	7.0
	7.0
	7.0
	6.9
	6.9
	6.9
	6.8
	6.7
	6.6
TOTAL	1055

$\overline{X}$ = 7.0

S = 0.2

Median = 7.0

95% Confidence Interval

$6.8 \leq \mu \leq 7.2$

$\overline{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent Turbidity During Storm Events

	Turbidity Jackson Units
	340
	332
	326
	252
	238
	238
	230
	223
	210
	210
	210
	192
	186
	50
TOTAL	3237

$\overline{X}$ = 231 J.U.

S = 73 J.U.

Median = 226

95% Confidence Interval

$226 \leq \mu \leq 236$

$\overline{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent Suspended Solids and Volatile Suspended Solids Concentrations During Rain Events

Suspended Solids mg/l	Volatile Suspended Solids mg/l
987	377
788	333
775	333
730	282
665	263
520	231
484	220
438	144
425	
405	
386	
385	
377	
329	
317	

$\bar{X}$ = 534 mg/l
S = 197 mg/l
Median = 438 mg/l
95% Confidence Interval
$526 \leq \mu \leq 542$

$\bar{X}$ = 273 mg/l
S = 75 mg/l
Median = 272
95% Confidence Interval
$387 \leq \mu \leq 405$

$\bar{X}$ = Sample Arithmetic Mean
S = Standard Deviation
μ = True Population Arithmetic Mean

Influent BOD Concentrations During Rain Events

BOD mg/l
440
282
245
242
202
202
200
190
165
160
148
147
139

$\bar{X}$ = 212 mg/l

S = 80.8 mg/l

Median = 200 mg/l

95% Confidence Interval

$207 \leq \mu \leq 217$

$\bar{X}$ = Sample Arithmetic Mean
S = Standard Deviation
μ = True Population Arithmetic Mean

Influent Total Solids and Total Volatile Solids Concentrations During Rain Events

Total Solids mg/l	Total Volatile Solids mg/l
1282	588
1216	410
1190	410
1073	406
1061	360
929	303
820	294
812	
777	
777	
753	
750	
721	
677	
647	
602	

$\bar{X}$ = 880 mg/l
S = 209 mg/l
Median = 794 mg/l
95% Confidence Interval
$872 \leq \mu \leq 888$

$\bar{X}$ = 396
S = 98
Median = 406
95% Confidence Interval
$387 \leq \mu \leq 405$

$\bar{X}$ = Sample Arithmetic Mean
S = Standard Deviation
μ = True Population Arithmetic Mean

Influent Total Phosphate Concentrations During Rain Events

Total Phosphate mg/l
68
50
35
29
26
24
24
24
23
21
18
17
16
12

$\overline{X}$ = 27..6 mg/l

S = 14.3 mg/l

Median = 24 mg/l

95% Confidence Interval
$25.4 \leq \mu \leq 29.8$

$\overline{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

Influent Nitrogen During Storm Events

	Nitrogen mg/l
	25.2
	24.0
	21.8
	20.3
	17.9
	17.9
	15.7
	15.4
	14.8
	14.2
	13.8
	11.4
	10.4
	8.2
TOTAL	231.0

$\overline{X}$ = 16.5 mg/l

S = 5.4 mg/l

Median = 15.6 mg/l

95% Confidence Interval
$15.2 \leq \mu \leq 17.8$

$\overline{X}$ = Sample Arithmetic Mean

S = Standard Deviation

μ = True Population Arithmetic Mean

CALCULATIONS

Computations of the mean removal rates of suspended solids, BOD, total solids, total phosphate and total nitrogen during rain events using various chemical treatments. All mechanical equipment on stream.

Waste Flow Rate = 350 GPM
ΔP = 50 psi
Air Feed Rate = 30 cfm

95% confidence interval was calculated using values of "t" found in Table II in the Manual of Experimental Statistics (37).

$$S = \sqrt{\frac{(X-X)^2}{n-1}}$$

Where
X = Removal Rates
$\overline{X}$ = Mean Sample Removal Rate
μ = Mean Population Removal Rate
n = Number of Observations

$$\overline{X} - t\,\frac{S}{\sqrt{n}} \leq \mu \leq t\,\frac{S}{\sqrt{n}} + \overline{X}$$

Suspended Solids Removal During

Rain Events Using No Chemical Treatment

X	$X-\overline{X}$	$(X-\overline{X})^2$
79	10	100
71	2	4
56	-13	169
206		273
69		

$\overline{X} = 69$

$$S = \sqrt{\frac{273}{2}} = 11.7$$

If $Q \geq 4.303$, Reject 56 **

$$t = \frac{13(1.732)}{11.7} = 1.924 \quad \text{cannot reject 56}$$

$$69 - \frac{4.303(11.7)}{1.732} \leq \mu \leq \frac{4.303(11.7)}{1.732} + 69$$

$$69 - 29.1 \leq \mu \leq 69 + 29.1$$

$$39.9 \leq \mu \leq 98.1$$

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods. (38)

Suspended Solids Removal During Rain Events

Using Alum Only

X	$X-\bar{X}$	$(X-\bar{X})^2$
85	23	529
71	9	81
66	4	16
44	18	324
43	19	361
309		1311
62		

$$S = \sqrt{\frac{1311}{4}} = 18.1$$

If $t \geq 2.571$, Reject 43 *

$$t = \frac{19\sqrt{5}}{18.1} = 2.35$$

Cannot Reject 43

If $t \geq 2.571$, reject 85

$$t = \frac{23\sqrt{5}}{18.1} = 2.841$$

Reject 85

X	$X-\bar{X}$	$(X-\bar{X})^2$
71	15	225
66	10	100
44	-12	144
43	-13	169
224		638
56		

$\bar{X} = 56$

$$S = \sqrt{\frac{638}{3}} = 16.03$$

If $t \geq 2.776$, Reject 71

$$t = \frac{15\sqrt{4}}{16.03} = 1.871, \text{ Cannot Reject 71}$$

$$56 - \frac{2.776(16.03)}{2} \leq \mu \leq \frac{2.776(16.03)}{2} + 56$$

$$56 - 22.2 \leq \mu \leq 56 + 22.2$$

$$33.8 \leq \mu \leq 78.2$$

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods.

Suspended Solids Removal During Rain Events Using Alum and Tretolite (Continued)

X	$X-\bar{X}$	$(X-\bar{X})^2$
85	3	9
85	3	9
84	2	4
82	0	0
75	-7	49
411		71
82		

$S = \sqrt{\frac{71}{4}} = \sqrt{17.75} = 4.213$

If $t \geq 2.776$, reject 75 **

$t = \frac{7\sqrt{5}}{4.2} = 3.727$, Reject 75

X	$X-\bar{X}$	$(X-\bar{X})^2$
85	1	1
85	1	1
84	0	0
82	-2	4
336		
84		

$S = \sqrt{\frac{6}{3}} = \sqrt{2} = 1.414$

If $t \geq 3.182$, Reject 82 **

$t = \frac{2\sqrt{4}}{1.414} = 2.828$ Cannot Reject 82

$\bar{X} = 84$; $S = 1.414$

$$\bar{X} = \frac{t\,s}{n} \leq \mu \leq X + \frac{t\,s}{n}$$

$$84 - \frac{3.182(1.414)}{2} \leq \mu \leq 84 + \frac{3.182(1.414)}{2}$$

$$84 - 2.25 \leq \mu \leq 84 + 2.25$$

$$81.75 \leq \mu \leq 86.25$$

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods.

Suspended Solids Removal During Rain Events

Using Alum and Tretolite

X	$X-\bar{X}$	$(X-\bar{X})^2$
85	7	49
85	7	49
84	6	36
82	4	16
75	- 3	9
75	- 3	9
74	- 4	16
66	-12	144
626		328
78		

$$S = \sqrt{\frac{328}{7}} = \sqrt{46.86} = 6.85$$

If $t \geq 2.365$, Reject 66 **

for $X = 66$, $t = \frac{12\sqrt{8}}{6.85} = 4.95$

Reject 66

X	$X-\bar{X}$	$(X-\bar{X})^2$
85	5	26
85	5	25
84	4	16
82	2	4
75	-5	25
75	-5	25
74	-6	36
560		156
80		

$$S = \sqrt{\frac{156}{6}} = \sqrt{26} = 5.099$$

If $t \geq 2.447$, Reject 74 **

for $X = 74$, $t = \frac{6\sqrt{7}}{5.1} = 3.116$

Reject 74

X	$X-\bar{X}$	$(X-\bar{X})^2$
85	4	16
85	4	16
84	3	9
82	1	1
75	-6	36
75	-6	36
486		114
81		

$$S = \sqrt{\frac{114}{5}} = \sqrt{22.8} = 4.775$$

If $t \geq 2.571$, Reject 75 **

for $X = 75$; $t = \frac{6\sqrt{6}}{4.8} = 2.811$

Reject 75

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods.

ONE WAY ANALYSIS OF VARIANCE

SUSPENDED SOLIDS REMOVAL DURING RAIN EVENTS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\overline{X}$
Rain Events						
No Chemicals	206	42436	14418	3	14145	79
Alum	224	50176	13182	4	12544	56
Alum + Tretolite	336	112896	33855	4	28224	84
Totals	766	205508	61455	11	54913	

$k = 3$
$k - 1 = 2$
$N = 11$
$N - k = 8$
$\alpha = 0.05$
$F = 4.46$

$T = 766$

$$C = \frac{T^2}{N} = \frac{(766)^2}{11} = \frac{586756}{11} = 53341$$

$$SSB = \Sigma \frac{T_i^2}{n} - C = 54913 - 53341 = 1572$$

$$SST = \Sigma\Sigma X_i^2 - C = 61455 - 53341 = 8114$$

$$SSE = SST - SSB = 8114 - 1572 = 6542$$

$$MSB = \frac{SSB}{k-1} = \frac{1572}{2} = 786$$

$$MSE = \frac{SSE}{N-k} = \frac{6542}{8} = 817.75$$

$$F = \frac{MSB}{MSE} = 0.96$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squa
Between Samples	2	1572	786
Error	8	6542	818
Total	10	8114	

TABLE D-1

One way analysis of variance of suspended solids removal during rain events using various chemical treatments. All mechanical equipment on stream. Chemical treatments include (1) no chemicals, (2) alum only, and (3) alum plus Tretolite Fr-50.

Null Hypothesis

H_o: There is no significant difference between the mean rates of TSS removal for the modes of operation listed above.

Alternate Hypothesis

H_a: There is a significant difference between the mean rates of Suspended Solids removal for the modes of operation listed above.

$\alpha = 0.05$

$F_\alpha = 4.46$

Criteria: Reject H_o if $F > F$, reserve judgement if $F \leq F_\alpha$

Result: $F = 0.134$

Decision: F is less than F_α, therefore cannot reject H_o. There is no apparent significant difference between the mean suspended solids removal rates for the modes of operations listed above.

To determine where the difference between these mean exists, a modified version of Duncan's Multiple Range Test (39) was used.

BOD Removal During Rain Events
Using No Chemical Treatment

X	$X-\bar{X}$	$(X-\bar{X})^2$
69	29	841
35	- 5	25
15	-25	625
119		1491
39.7		

$\bar{X} = 40$

$$S = \sqrt{\frac{1491}{2}} = \sqrt{745.5} = 27.3$$

$$5 \leq \mu \leq 80 \quad *$$

T.S. Removal During Rain Events
Using No Chemical Treatment

X	$X-\bar{X}$	$(X-\bar{X})^2$
45	11	121
29	- 5	25
29	- 5	25
103		171
34.3		

$\bar{X} = 34$

$$S = \sqrt{\frac{171}{2}} = \sqrt{85.5} = 9.25$$

$$34.3 - \frac{9.25(4.303)}{\sqrt{3}} \leq \mu \leq 34.3 + \frac{9.25(4.303)}{\sqrt{3}}$$

$$34.3 - 23.0 \leq \mu \leq 34.3 + 23.0$$

$$11 \leq \mu \leq 57$$

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

BOD Removal During

Rain Events Using Alum Only

X	$X-\overline{X}$	$(X-\overline{X})^2$
59	23	529
31	- 4	16
30	- 5	25
20	-15	225
139		795
34.75		

$\overline{X} = 35$

$$S = \sqrt{\frac{795}{3}} = \sqrt{265} = 16.3$$

Reject 58 if $Q \geq 1.53$ **

$$Q = \frac{23}{16.3} = 1.41\text{, Cannot Reject 58}$$

$$35 - \frac{16.3(3.182)}{\sqrt{4}} \leq \mu \leq 35 + \frac{16.3(3.182)}{\sqrt{4}}$$

$$35 - 25.9 \leq \mu \leq 35 + 25.9$$

$$9 \leq \mu \leq 61$$

T.S. Removal During

Rain Events Using Alum Only

X	$X-\overline{X}$	$(X-\overline{X})^2$
48	12	144
36	0	0
35	- 1	1
23	-12	144
142		289
35.5		

$\overline{X} = 36$

$$S = \sqrt{\frac{289}{3}} = \sqrt{\frac{17}{3}} = 9.82$$

$$35.5 - \frac{(9.82)(3.182)}{\sqrt{2}} \leq \mu \leq 35.5 + \frac{(9.82)(3.182)}{\sqrt{2}}$$

$$35.5 - 12.4 \leq \mu \leq 35.5 + 12.4$$

$$23 \leq \mu \leq 48$$

** Application of Chauvenet's Criteria, critical values found in Table A-6, Basic Statistical Methods.

BOD Removal During Rain Events

Using Alum + Tretolite

X	$X-\overline{X}$	$(X-X)^2$
82	14	196
77	9	81
74	6	36
72	4	16
70	2	4
64	- 4	16
35	33	1089
474		1438
67.7		

$$S = \sqrt{\frac{1438}{6}} = \sqrt{239.7} = 15.5$$

Reject 35 if $Q \geq 1.80$ **

$$Q = \frac{33}{15.5} = 2.13, \text{ Reject } 35$$

X	$X-\overline{X}$	$(X-\overline{X})^2$
82	9	81
77	4	16
74	1	1
72	- 1	1
70	- 3	9
64	- 9	81
439		189
73		

$\overline{X} = 73$

$$S = \sqrt{\frac{189}{5}} \quad \sqrt{37.8} = 6.15$$

$$73 - \frac{6.15(2.571)}{\sqrt{6}} \leq \mu \leq 73 + \frac{6.15(2.571)}{\sqrt{6}}$$

$$73 - 6.5 \leq \mu \leq 73 + 6.5$$

$$67 \leq \mu \leq 79$$

** Application of Chauvenet's Criteria, critical values found in Table A-6, Basic Statistical Methods.

ONE WAY ANALYSIS OF VARIANCE

BOD REDUCTION DURING RAIN EVENTS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\bar{X}$
No Chemicals	119	14161	6211	3	4720	40
Alum	139	19321	5624	4	4830	35
Alum + Tretolite	439	192721	32309	6	32120	73
Totals	697		44144	13	41670	

$k = 3$
$k - 1 = 2$
$N = 13$
$N - k = 10$
$\alpha = 0.05$
$F = 4.10$

$$C = \frac{T^2}{N} = \frac{(697)^2}{13} = \frac{485809}{13} = 37370$$

$$SSB = \sum \frac{T_i^2}{n} - C = 41670 - 37370 = 4300$$

$$SST = \sum\sum X_i^2 - C = 44144 - 37370 = 6774$$

$$SSE = SST - SSB = 6774 - 4300 = 2474$$

$$MSB = \frac{SSB}{k-1} = \frac{4300}{2} = 2150$$

$$MSE = \frac{SSE}{N-k} = \frac{2474}{10} = 247$$

$$F = \frac{MSB}{MSE} = \frac{2150}{247} = 8.70$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	2	4300	2150
Error	10	2474	247
Total	13	6775	

DUNCAN'S MULTIPLE RANGE TEST (39)
(MODIFIED VERSION)
BOD REDUCTION DURING RAIN EVENTS

		$\bar{X}$
1.	Alum	35
2.	Alum + Tretolite	73

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1 + r_2}} = \sqrt{\frac{(247)\ 2}{10}} = \sqrt{49.4} = 7.05$$

r_1 & r_2 = Sample Sizes

$\propto = 0.05;\ N_2 = 10$

P = 2

SSR	3.15
LSR = (SSR)$S_{\bar{x}}$	22.21

Ranked Means	1	2
	35	73

Means	Diff	P	LSR
201	38	2	22.2

Decision: Difference is significant.

		$\bar{X}$
1.	No Chemicals	40
2.	Alum + Tretolite	73

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1 + r_2}} = \sqrt{\frac{(247)\ 2}{9}} = 1/3\ \sqrt{494} = 1/3\sqrt{(22.2)} = 7.40$$

r_1 & r_2 = Sample Sizes

$\propto = 0.05;\ N_2 = 10$

P = 2

SSR	3.15
LSR = (SSR) $S_{\bar{x}}$	23.31

Ranked Means	1	2
	40	73

Means	Diff	P	LSR
201	33	2	23.3

Decision: Difference is significant.

DUNCAN'S MULTIPLE RANGE TEST
(MODIFIED VERSION)
BOD REDUCTION DURING RAIN EVENTS

		$\bar{X}$
1.	Alum	35
2.	No Chemicals	40

$$S_{\bar{x}} = \sqrt{\frac{(MSE)\,2}{r_1 + r_2}} = \sqrt{\frac{(247)\,2}{7}} = \sqrt{70.57} = 8.40$$

r_1 & r_2 = Sample Sizes

$\alpha = 0.05;\ N_2 = 10$

$P = 2$

SSR	3.15
LSR = (SSR)$S_{\bar{x}}$	26.46

Ranked Means	1	2
	35	40

Mean	Diff	P	LSR
201	5	2	26.5

Decision: Difference is not significant.

DUNCAN'S MULTIPLE RANGE TEST

(MODIFIED VERSION)

BOD REDUCTION DURING RAIN EVENTS

	$\overline{X}$
1. Alum	35
2. Alum + Tretolite	73

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1 + r_2}} = \sqrt{\frac{(2150)2}{10}} = \sqrt{430} = 20.74$$

r_1 & r_2 = Sample Sizes

$\alpha = 0.05;\ N_2 = 10$

$P = 2$

SSR	3.15
LSR = $(SSR)S_{\bar{x}}$	65.33

	1	2
Ranked Means	35	73

Means	Diff	P	LSR
201	38	2	653

Decision: Difference is not significant.

	$\overline{X}$
1. No Chemicals	40
2. Alum + Tretolite	73

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1+r_2}} = \sqrt{\frac{(2150)2}{9}} = 1/3\ \sqrt{4300} = 1/3\ (65.57) = 21.86$$

r_1 & r_2 = Sample Sizes

$\alpha = 0.05;\ N_2 = 10$

$P = 2$

SSR	3.15
LSR = $(SSR)S_{\bar{x}}$	68.86

	1	2
Ranked Means	40	73

Means	Diff	P	LSR
2-1	33	2	6886

Decision: Difference is not significant.

DUNCAN'S MULTIPLE RANGE TEST

(MODIFIED VERSION)

BOD REDUCTION DURING RAIN EVENTS

		$\overline{X}$
1.	Alum	35
2.	No Chemicals	40

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1 + r_2}} = \sqrt{\frac{(2150)2}{7}} = \sqrt{655.7} = 24.79$$

r_1 & r_2 = Sample Sizes

$\alpha = 0.05$; $N_2 = 10$

$P = 2$

SSR	3.15
LSR = $(SSR)S_{\bar{x}}$	78.08

	1	2
Ranked Means	35	40

Means	Diff	P	LSR
2-1	5	2	78.1

Decision: Difference is not significant.

TABLE D-2

One way analysis of variance for BOD reduction during rain events using various chemical treatments. All mechanical equipment on stream. Chemical treatments include (1) no chemicals, (2) alum only, and (3) Alum plus Tretolite FR-50.

Null Hypothesis

H_o: There is no significant difference between the mean rates of BOD reduction for the modes of operation listed above.

Alternate Hypothesis

H_a: There is a significant difference between the mean rates of BOD reduction for the modes of operation listed above.

α = 0.05

$F\alpha$ = 4.10

Criteria: Reject H_o if $F > F$, reserve judgement if $F \leq F\alpha$

Result: F = 8.70

Decision: F is greater than $F\alpha$, therefore reject H_o. There is an apparent significant difference between the mean rates of BOD reduction as listed above.

The application of a modified version of Duncan's Multiple Range Test indicates that a difference exists between the mean reduction rate of BOD when alum and Tretolite FR-50 are used and the other treatments.

Total Solids Removal During Rain Events Using Alum + Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
64	12	144
57	5	25
54	2	4
54	2	4
53	1	1
46	6	36
34	18	324
362		538
51.7		

$\overline{X} = 52$

$$S = \sqrt{\frac{538}{6}} = \sqrt{76.9} = 8.77$$

$$51.7 - \frac{8.77(2.447)}{\sqrt{7}} \leq \mu \leq 51.7 + \frac{(8.77)(2.447)}{\sqrt{7}}$$

$$51.7 - 8.5 \leq \mu \leq 51.7 + 8.5$$

$$43 \leq \mu \leq 60$$

Total Phosphate Removal During Rain Events Using Alum + Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
100	26	676
91	17	289
83	9	81
81	7	49
58	-16	256
53	-21	441
52	-22	484
513		2276

$\overline{X} = 74$

$$S = \sqrt{\frac{2276}{6}} = \sqrt{379.3} = 19.47$$

$$74 - \frac{(19.47)(2.447)}{\sqrt{7}} \leq \mu \leq 74 + \frac{(19.47)(2.447)}{\sqrt{7}}$$

$$74 - 18 \leq \mu \leq 74 + 18$$

$$56 \leq \mu \leq 92$$

ONE WAY ANALYSIS OF VARIANCE

TOTAL SOLIDS REMOVAL DURING RAIN EVENTS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\bar{X}$
No Chemicals	103	10609	3707	3	3536	34
Alum	142	20164	5354	4	5041	36
Alum & Tretolite FR-SO	362	131044	19258	7	18721	52
TOTALS	607		28319	14	27298	

k = 3
k-1 = 2
N = 14
N-k = 11

α = .05
F = 3.98

T = 607

$$C = \frac{T^2}{N} = \frac{607^2}{14} = \frac{368449}{14} = 26318$$

$$SSB = \sum \frac{T_i^2}{n} - C = 27298 - 26318 = 980$$

$$SST = \sum \sum X_i^2 - C = 28319 - 26318 = 2001$$

$$SSE = SST - SSB = 2001 - 980 = 1021$$

$$MSB = \frac{SSB}{k-1} = \frac{980}{2} = 490$$

$$MSE = \frac{SSE}{N-k} = \frac{1021}{11} = 92.8$$

$$F = \frac{MSB}{MSE} = \frac{490}{92.8} = 5.28$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	2	980	490
Error	11	1021	92.8
Total	13	2001	5.28

TABLE D-3

One way analysis of variance of total solids removal during rain events using various chemical treatments. All mechanical equipment on stream. Chemical treatments include: (1) no chemicals; (2) alum only; (3) Alum plus Tretolite FR-50.

Null Hypothesis

H_o: There is no significant difference between the mean rates of total solids removal for the modes of operation listed above.

Alternate Hypothesis

H_a: There is a significant difference between the mean rates of total solids removal for the modes of operation listed above.

α = 0.05

F_α = 3.98

Criteria: Reject H_o if $F > F$, reserve judgement if $F \leq F_\alpha$

Result: $F = 5.28$

Decision: F is greater than F_α , therefore reject H_o. There is a significant difference between the mean rates of Total Solids removal during rain events.

An analysis using a modified version of Duncan's Multiple Range Test indicates the difference exists between the mean removal rate of total solids when alum and Tretolite FR-50 is used and the other treatments.

Total Phosphate Removal During Rain Events Using Alum Only

$\overline{X}$	$X-\overline{X}$	$(X-\overline{X})^2$
48	18.5	342.25
11	-18.5	342.25
59		684.5
29.5		

$\overline{X} = 30$

$S = \sqrt{684.5} = 26.16$

$2 \leq \mu \leq 71$ *

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* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

Total Phosphate Removal During Rain Events

Using No Chemical Treatment

X	$X-\bar{X}$	$(X-\bar{X})^2$
83	35.5	1260.25
12	-35.5	1260.25
95		2520.5
47.5		

$\bar{X} = 48$

$S = \sqrt{2520.5} = 50.2$

$6 \le \mu \le 80$ *

Total Nitrogen Removal During Rain Events

Using No Chemical Treatment

X	$X-\bar{X}$	$(X-\bar{X})^2$
10	6	36
4	0	0
1	3	9
0	4	16
15		61
3.75		

$\bar{X} = 4$

$S = \sqrt{\frac{61}{3}} = \sqrt{20.3} = 4.51$

$0 \le \mu \le 50\%$ *

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

Total Nitrogen Removal During Rain Events Using Alum + Tretolite FR-50

Total Nitrogen mg/l		
X	X-X	$(X-\bar{X})^2$
15	8.6	73.96
12	5.6	31.36
10	3.6	12.96
8	1.6	2.56
0	6.4	40.96
0	6.4	40.96
0	6.4	40.96
45		243.72
6.4		

$$S = \sqrt{\frac{244}{6}} = \sqrt{60.7} = 7.79$$

$$0\,\% \leq \mu \leq 45\%\ *$$

$\bar{X} = 6$

Suspended Solids removal during an isolated rain event using alum + Tretolite FR-50, waste flow rate = 200 GPM, p=50 psi, air feed rate =25 cfm.

Suspended Solids mg/l		
In	Out	%R
775	79	90

Suspended solids removal during an isolated rain event using 150 mg/l lime and 5 mg/l Drew Floc 410 waste flow rate =350 GPM, p=50 psi, air feed rate =30 cfm.

Suspended Solids

In	Out	% Removal
220	175	21

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

ONE WAY ANALYSIS OF VARIANCE

TOTAL PHOSPHATE REMOVAL DURING RAIN EVENTS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\overline{X}$
No Chemicals	95	9025	7033	2	4512	48
Alum	59	3481	2425	2	1740	30
Alum + Tretolite FR-50	518	268325	40608	7	38332	74
Totals	672		50066	11	44584	

$k = 3$
$k - 1 = 2$
$N = 11$
$N - k = 8$
$\alpha = 0.05$
$F_\alpha = 4.26$

$T = 672$

$$C = \frac{T^2}{N} = \frac{672^2}{11} = \frac{451584}{11} = 41053$$

$$SSB = \sum\frac{T_i^2}{n} - C = 44584 - 41053 = 3531$$

$$SST = \sum\sum X_i^2 - C = 50066 - 41053 = 9013$$

$$SSE = SST - SSB = 9013 - 3531 = 5482$$

$$MSB = \frac{SSB}{k-1} = \frac{3531}{2} = 1766$$

$$MSE = \frac{SSE}{N-k} = \frac{5482}{8} = 685$$

$$F = \frac{MSB}{MSE} = \frac{1766}{685} = 2.58$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	2	3531	1766
Error	8	5482	685
Total	10	9013	

TABLE D-4

One way analysis of variance for the removal of total phosphates during rain events using various chemical treatments. All mechanical equipment on stream. Chemical treatments include (1) no chemicals, (2) alum only, and (3) alum plus Tretolite FR-50.

Null Hypothesis

H_o: There is no significant difference between the mean rates of total phosphate removal for the modes of operation listed in Table 4.

Alternate Hypothesis

H_a: There is a significant difference between the mean rates of total phosphate removal fro the modes of operation listed in Table 4.

α = 0.05

F_α = 4.26

Criteria: Reject H_o if $F > F$, reserve judgement if $F \leq F_\alpha$

Result: $F = 2.58$

Decision: F is less than F_α , therefore reserve judgement. There is no significant difference in the TS removal rates during rain events.

Computations of The mean rates of suspended solids, BOD, total solids, total phosphate, and total nitrogen removal using The various combinations of the screen, cyclones and flotation cell.

Waste Flow Rate	=	350 GPM
ΔP	=	50 psi
Air Feed Rate	=	30 cfm

95% confidence interval was calculated using values of " t " found in Table II in the Manual of Experimental Statistics.

$$S = \sqrt{\frac{(X-\bar{X})^2}{n-1}}$$

Where
X = Removal Rates
$\bar{X}$ = Mean Sample Removal Rate
n = Number of Observations
μ = Mean Population Removal Rate

$$\bar{X} - t \frac{s}{\sqrt{n}} \leq \mu \leq t \frac{s}{\sqrt{n}} + \bar{X}$$

Removal of Suspended Solids Using Screen and Flotation Tank

X	$X-\overline{X}$	$(X-\overline{X})^2$
58	9	81
49	0	0
48	- 1	1
48	- 1	1
41	8	64
244	Totals	147

$\overline{X} = 49$

$$S = \sqrt{\frac{147}{4}} = \frac{12.12}{2} = 6.06$$

$$49 - \frac{6.06(2.776)}{5} \leq \mu \leq 49 + \frac{6.06(2.776)}{5}$$

$$49 - 7.5 \leq \mu \leq 49 + 7.5$$

$$41.5 \leq \mu \leq 56.5$$

Removal of Suspended Solids Using Screen, Primary Cyclone and Flotation Tank

X	$X-\overline{X}$	$(X-\overline{X})^2$
60	11	121
55	6	36
53	4	16
52	3	9
51	2	4
42	-7	49
41	-8	64
39	-10	100
393	Totals	399
49.1		

$\overline{X} = 49$

$$S = \sqrt{\frac{399}{7}} = \frac{19.975}{2.646} = 7.5$$

$$49 - \frac{(2.365)(7.5)}{\sqrt{8}} \leq \mu \leq 49 + \frac{(2.365)(7.5)}{\sqrt{8}}$$

$$49 - 6.3 \leq \mu \leq 49 + 6.3$$

$$42.7 \leq \mu \leq 55.3$$

Removal of Suspended Solids Using Two Secondary Cyclones and Flotation Tank

X	$X-\bar{X}$	$(X-\bar{X})^2$
67	2	4
66	1	1
61	- 4	16
194		21
64.7		

$\bar{X} = 65$

$$S = \sqrt{\frac{21}{2}} = \frac{4.583}{1.414} = 3.24$$

$$64.7 - \frac{3.24(4.3)}{\sqrt{3}} \leq \mu \leq 64.7 + \frac{3.24(4.3)}{\sqrt{3}}$$

$$64.7 - 8.0 \leq \mu \leq 64.7 + 8.0$$

$$56.7 \leq \mu \leq 72.7$$

Removal of Suspended Solids Using Screen, Three Secondary Cyclones and Flotation Tank

X	$X-\bar{X}$	$(X-\bar{X})^2$
60	7	49
59	6	36
54	1	1
53	0	0
49	4	16
43	10	100
318		202
53		

$\bar{X} = 53$

$$S = \sqrt{\frac{202}{5}} = \frac{14.213}{2.236} = 6.35$$

$$53 - \frac{(6.35)(2.571)}{6} \leq \mu \leq 53 + \frac{(6.35)(2.571)}{6}$$

$$53 - 6.7 \leq \mu \leq 53 + 6.7$$

$$46.3 \leq \mu \leq 59.7$$

ONE WAY ANALYSIS OF VARIANCE

SUSPENDED SOLIDS REMOVAL USING VARIOUS COMBINATIONS OF SEPARATORY EQUIPMENT

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\bar{X}$
Screen	244	59536	12054	5	11907	49
Screen & Primary Cyclone	393	154449	19703	8	19306	49
Screen & 3 Secondary Cyclones	318	101124	17056	6	16854	53
Screen & 2 Secondary Cyclones	194	37636	12535	3	12545	65
TOTALS	1149		61348	22	60612	

$k = 4$
$k-1 = 3$
$N = 22$
$N-k = 18$
$\alpha = 0.05$
$F = 3.16$

$T = 1149$

$C = \frac{T^2}{N} = \frac{(1149)^2}{22} = \frac{1320201}{22} = 60009$

$SSB = \sum \frac{T^2}{n} - C = 60612 - 60009 = 603$

$SST = \sum\sum X_i^2 - C = 61348 - 60009 = 1339$

$SSE = SST - SSB = 736$

$MSB = \frac{SSB}{k-1} = \frac{603}{3} = 201$

$MSE = \frac{SSE}{N-k} = \frac{736}{18} = 40.9$

$F = \frac{MSB}{MSE} = \frac{201}{40.9} = 4.91$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	3	603	201
Error	18	736	40.9
Total	21	1339	

DUNCAN'S MULTIPLE RANGE TEST

(MODIFIED VERSION)

SUSPENDED SOLIDS REMOVAL USING VARIOUS COMBINATIONS OF SEPARATORY EQUIPMENT

Non-Rain Events

1. Screen, primary cyclones, flotation cell
2. Screen, 3 secondary cyclones, flotation cell

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1+r_2}} = \sqrt{\frac{(40.9)2}{14}} = 5.843 = 2.42$$

r_1 & r_2 = Sample sizes

$\propto = 0.05; N_2 = 18$

P = 2

SSR	2.97
LSR = (SSR)$S_{\bar{x}}$	7.19

	1	2
Ranked Means	49	53

Means	Diff	P	LSR
B-A	4	2	7.19

Decision: The difference between the mean removal rates is not significant.

DUNCAN'S MULTIPLE RANGE TEST

(MODIFIED VERSION)

Suspended solids removal using various combinations of Separatory equipment.

Non-Rain Events

	$\overline{X}$
1. Screen, flotation cell, 3 secondary cyclones	53
2. Screen, flotation cell, 2 secondary cyclones	65

$$S_{\overline{x}} = \sqrt{\frac{(MSE)2}{r_1+r_2}} = \sqrt{\frac{(40.9)2}{9}} = (2.13)(1.414) = 3.014$$

r_1 & r_2 = Sample **sizes**

$\propto = .05;\ N_2 = 18$

P = 2

SSR	2.97
LSR = (SSR)$S_{\overline{x}}$	8.95

	1	2
Ranked Means	53	65

Means	Diff	P	LSR
B-A	12	2	8.95

Decision: There is a significant difference between the two mean rates of **suspended solids removal.**

BOD Removal Using Screen and Flotation Tank

X	$X-\bar{X}$	$(X-\bar{X})^2$
47	20	400
26	1	1
9	-18	324
82		725
27.3		

$\bar{X} = 27$

$$S = \sqrt{\frac{725}{2}} = \sqrt{362.5} = 19.04$$

$$0 \leq \mu \leq 75 \quad *$$

Total Solids Removal Using Screen and Flotation Tank

X	$X-\bar{X}$	$(X-\bar{X})^2$
35	8	64
30	3	9
15	12	144
80		217
26.7		

$\bar{X} = 27$

$$S = \sqrt{\frac{217}{2}} = \sqrt{108.5} = 10.4$$

$$0 \leq \mu \leq 75 \quad *$$

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

TABLE D-5

One way analysis of variance for the suspended solids removal rates using the various combinations of the screen cyclones and flotation cell. No chemicals in use.

Null Hypothesis

H_o: There is no significant difference between the mean total suspended solids removal rates for the five modes of operation shown in Table 2.

Alternate Hypothesis

H_a: There is a significant difference between the mean total suspended solids removal rate for the five modes of operation shown in Table 2.

$\alpha = 0.05$

$F_\alpha = 3.16$

Criteria: Reject H_o if $F > F$; reserve judgement if $F \leq F_\alpha$.

Result: $F = 4.91$

Decision: F is greater than F_α , therefore reject H_o; there is a significant difference between these mean total suspended solids removal rates.

BOD Removal Using Screen, Primary Cyclone, and Flotation Tank

X	$X-\overline{X}$	$(X-\overline{X})^2$
57	22	484
36	1	1
36	1	1
33	- 2	4
14	-21	441
176		931
35.2		

$\overline{X} = 35$

$$S = \sqrt{\frac{931}{4}} = \sqrt{237.8} = 15.25$$

$$35 - \frac{15.3(2.776)}{\sqrt{5}} \leq \mu \leq 35 + \frac{15.3(2.776)}{\sqrt{5}}$$

$$35 - 19 \leq \mu \leq 35 + 19$$

$$16 \leq \mu \leq 54$$

BOD Removal Using Screen, Two Secondary Cyclones and Flotation Tank

X	$X-\overline{X}$	$(X-\overline{X})^2$
75	34	1156
29	-12	144
19	-22	484
123		1784
41		

$\overline{X} = 41$

$$S = \sqrt{\frac{1784}{2}} = \sqrt{892} = 29.9$$

$$5 \leq \mu \leq 80 \; *$$

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

BOD Removal Using Screen, Three Cyclones and Flotation Tank

X	$X-\overline{X}$	$(X-\overline{X})^2$
44	8	64
44	8	64
40	4	16
16	20	400
144		544
36		

$\overline{X} = 36$

$$S = \sqrt{\frac{544}{3}} = \sqrt{181.3} = 13.5$$

$$36 - \frac{13.5(3.182)}{\sqrt{4}} \leq \mu \leq 36 + \frac{13.5(3.182)}{\sqrt{4}}$$

$$15 \leq \mu \leq 57$$

Total Solids Removal Using Screen, Three Secondary Cyclones and Flotation Tank

X	$X-\overline{X}$	$(X-\overline{X})^2$
41	18	324
29	6	36
28	5	25
21	2	4
20	3	9
13	10	100
11	12	144
163		642
23.3		

$\overline{X} = 23$

$$S = \sqrt{\frac{642}{6}} = \sqrt{107} = 10.3$$

$$23 - \frac{10.3(2.447)}{\sqrt{7}} \leq \mu \leq 23 + \frac{10.3(2.447)}{\sqrt{7}}$$

$$23 - 9.5 \leq \mu \leq 23 + 9.5$$

$$13 \leq \mu \leq 33$$

ONE WAY ANALYSIS OF VARIANCE

BOD REDUCTION USING VARIOUS COMBINATIONS OF SEPARATORY EQUIPMENT

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\overline{X}$
All Equipment	130	16900	3556	5	3380	26
Screen & Flotation Cell	82	6724	2966	3	2241	27
Screen, Flotation Cell, Primary Cyclone	176	30976	7126	5	6195	35
Screen, Flotation Cell, 2 Secondary Cyclones	70	4900	1636	3	1633	23
Screen, Flotation Cell, 3 Secondary Cyclones	144	20736	5728	4	5184	36
TOTALS	602		21012	20	18633	

$k = 5$
$k-1 = 4$
$N = 20$
$N-k = 15$
$\alpha = 0.05$
$F_\alpha = 3.06$

$T = 602$

$$C = \frac{T^2}{N} = \frac{362404}{20} = 18120$$

$$SSB = \sum\frac{T_i^2}{n} - C = 18633 - 18120 = 513$$

$$SST = \sum\sum X_i^2 - C = 21012 - 18120 = 2892$$

$$SSE = SST - SSB = 2379$$

$$MSB = \frac{513}{4} = 128.25$$

$$MSE = \frac{2379}{15} = 158.6$$

$$F = \frac{MSB}{MSE} = \frac{128.25}{158.6} = 0.807$$

Source of Variation	**Degrees of Freedom**	**Sum of Squares**	**Mean Square**
Between Samples	4	513	128.25
Error	15	2379	158.6
Total	19	2892	

TABLE D-6

One way analysis of variance for the BOD reduction rates using the various combinations of the screen, cyclones and flotation cell. No chemicals were used.

Null Hypothesis

H_o: There is no significant difference between the rates of BOD reduction for the operational modes listed in Table 2.

Alternate Hypothesis

H_a: There is a significant difference between the rates of BOD reduction for the operational modes listed in Table 2.

$\alpha = 0.05$

$F_\alpha = 3.06$

Criteria: Reject H_o if $F > F$; reserve judgement if $F \leq F_\alpha$.

Result: $F = 0.807$

Decision: F is less than F_α ; reserve judgement.

This one-way analysis of variance indicates that any difference between the rates of BOD reduction in Table is due to chance and that **changes in auxillary equipment do not significantly affect** BOD reduction rates. Apparently flotation produces the major reduction in BOD.

Total Solids Removal Using Screen, Primary Cyclone and Flotation Tank

X	$X-\bar{X}$	$(X-\bar{X})^2$
27	10.5	110.25
23	6.5	42.25
13	3.5	12.25
3	13.5	182.25
66		347.00

$\bar{X} = 16$

$$S = \sqrt{\frac{347}{3}} = \sqrt{116} = 10.8$$

$$0\% \leq \mu \leq 65\% \; *$$

---

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

Total Solids Removal Using
Two Secondary Cyclones and Flotation Cell

X	$X-\bar{X}$	$(X-\bar{X})^2$
24	1	1
24	1	1
22	1	1
70		3
23		

$\bar{X} = 23$

$$S = \sqrt{\frac{3}{2}} = 1.225$$

$$23 - \frac{(1.225)(4.303)}{3} \leq \mu \leq 23 + \frac{(1.225)(4.303)}{3}$$

$$23 - 3 \leq \mu \leq 23 + 3$$

$$20 \leq \mu \leq 26$$

Total Solids Removal Using Screen, Three Secondary Cyclones, Flotation Tank With Alum and Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
61	0.5	.25
60	-0.5	.25
121		0.50
60.5		

$\overline{X} = 60$

$$S = \sqrt{\frac{0.50}{1}} = 0.707$$

$15\% \leq \mu \leq 100\%$ *

---

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

ONE WAY ANALYSIS OF VARIANCE

TOTAL SOLIDS REMOVAL USING VARIOUS COMBINATIONS OF SEPARATORY EQUIPMENT

	T_i	T_i^2	X^2	n	T_i^2/n	$\bar{X}$
All Equipment	134	17956	3390	7	2565	19
Screen Flotation Tank	80	6400	2350	3	2133	27
Screen,Primary Cyclone,Flotation Tank	66	4356	1436	4	1089	16
Screen, 3 Secondary Cyclone, Flotation Tank	121	14641	7321	2	7320	60
Screen 2 Secondary Cyclone,Flotation Tank	70	4900	1636	3	1633	23
Totals	471		16133	19	14740	

$k = 5$
$k-1 = 4$
$N = 19$
$N-k - 14$
$\alpha = 0.05$
$F = 3.11$

$T = 471$

$$C = \frac{T^2}{N} = \frac{471^2}{19} - \frac{221841}{19} = 11676$$

$$SSB = \sum \frac{T_i^2}{n} - C = 14740 - 11676 = 3064$$

$$SST = \sum\sum X_i^2 - C = 16133 - 11676 = 4457$$

$$SSE = SST - SSB = 4457 - 3064 = 1393$$

$$MSB = \frac{SSB}{k-1} = \frac{3064}{4} = 766$$

$$MSE = \frac{SSE}{N-k} = \frac{1393}{14} = 9.95$$

$$F = \frac{MSB}{MSE} = \frac{776}{9.95} = 78$$

Source of Variation	Degrees of Freedom	Sum of Square	Mean Square
Between samples	4	3064	766
Error	14	1393	9.95
Total	18	4457	

TABLE D-7

One way analysis of variance for removal of total solids using the various combinations of the screen, cyclones and flotation cell. No chemicals were used.

Null Hypothesis

H_o: There is no significant difference between the mean removal rates of total solids for the operational modes listed in Table 2.

Alternate Hypothesis

H_a: There is a significant difference between the mean removal rates of total solids for the operational modes listed in Table 2.

$\alpha = 0.05$

$F_\alpha = 3.11$

Criteria: Reject H_o if $F \geq F_\alpha$; reserve judgement if $F < F_\alpha$.

Result: $F = 78$

Decision: Cannot reject H_o; there is a significant difference between the rates of total solids removal. The difference exists between the total solids removal rate for the screen, 3 secondary cyclones, and flotation cell and the other treatments.

Total Phosphate Removal Using the Various Combinations of The Screen, Cyclones and Flotation Cell

X	$X-\bar{X}$	$(X-\bar{X})^2$
37	23	529
36	22	484
33	19	361
21	7	49
21	7	49
20	6	36
17	3	9
13	-1	1
10	-4	16
8	-6	36
8	-6	36
7	-7	49
6	-8	64
5	-9	81
4	-10	100
2	-12	144
2	-12	144
2	-12	144
252		2332
14		

$\bar{X} = 14$

$$S = \sqrt{\frac{2332}{17}} = \sqrt{137.2} = 11.71$$

$$14 - \frac{2.11(11.7)}{\sqrt{18}} \leq \mu \leq 14 + \frac{2.11(11.7)}{\sqrt{18}}$$

$$14 - 5.8 \leq \mu \leq 14 + 5.8$$

$$8 \leq \mu \leq 20$$

Total Nitrogen Removal Using the Various Combinations of The Screen, Cyclones and Flotation Cell

X	$X-\bar{X}$	$(X-\bar{X})^2$
*32		
*21		
10	5.6	31.36
8	3.6	12.96
8	3.6	12.96
8	3.6	12.96
6	1.6	2.56
6	1.6	2.56
5	0.6	.36
5	0.6	.36
5	0.6	.36
4	0.4	.16
1	3.4	11.56
0	4.4	19.36
0	4.4	19.36
0	4.4	19.36
0	4.4	19.36
66		144.24
4.4		

$\bar{X} = 4$

$$S = \sqrt{\frac{144.24}{14}} \quad \sqrt{10.3} = 3.21$$

$$4.4 - \frac{(2.145)(3.21)}{\sqrt{15}} \leq \mu \leq 4.4 + \frac{(2.145)(3.21)}{\sqrt{15}}$$

$$4.4 - 1.8 \leq \mu \leq 4.4 + 1.8$$

$$2.6 \leq \mu \leq 6.2$$

* Values disregarded in computation of mean.

Computations of the mean removal rates of suspended solids, BOD, total solids, total phosphate and total nitrogen using various chemical treatments. All mechanical separation equipment on stream.

Waste Flow Rate = 350 GPM

ΔP = 50 psi

Air Feed Rate = 30 cfm

95% confidence interval was calculated using values in Table II as found in the Manual of Experimental Statistics. ( )

$$S = \sqrt{\frac{(X-X)^2}{N-1}}$$

Where
X = Removal rates
$\bar{X}$ = Mean removal rate
N = Number of observations
μ = Mean population removal rate

$$X - t\frac{S}{\sqrt{N}} \le \mu \le t\frac{S}{\sqrt{N}} + \bar{X}$$

Removal of Suspended Solids Using No Chemical Treatment

X	$X-\bar{X}$	$(X-\bar{X})^2$
68	13	169
63	8	64
61	6	36
61	6	36
61	6	36
60	5	25
58	3	9
34	-21	441
27	-28	784
493	Totals	1600
55		

$$S = \sqrt{\frac{1600}{8}} = \sqrt{200} = 14.14$$

If $Q \geq 1.91$, Reject 27 **

$$Q = \frac{28}{14.14} = 1.98 \quad \underline{\text{Reject 27}}$$

X	$X-\bar{X}$	$(X-\bar{X})^2$
68	10	100
63	5	25
61	3	9
61	3	9
61	3	9
60	2	4
58	0	0
34	-24	576
466	Totals	732
58		

$$S = \sqrt{\frac{732}{7}} = \frac{27.055}{2.646} = 10.22$$

If $Q \geq 1.860$, Reject 34**

$$Q = \frac{24.}{10.22} = 2.348, \ \underline{\text{Reject 34}}$$

X	$X-\bar{X}$	$(X-\bar{X})^2$
68	6	36
63	1	1
61	-1	1
61	-1	1
61	-1	1
60	2	4
58	-4	16
432		60
62		

$$S = \sqrt{\frac{60}{6}} = 3.162$$

$$62 - \frac{3.162(2.447)}{\sqrt{7}} \leq \mu \leq 62 - \frac{3.162(2.447}{\sqrt{7}}$$

$$62 - 2.9 \leq \mu \leq 62 + 2.9$$

$$59.1 \leq \mu \leq 64.9$$

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods.

Removal of Suspended Solids Using Alum

X	$X-\overline{X}$	$(X-\overline{X})^2$
92	28	784
69	5	25
68	4	16
29	35	1225
258		2050
64		

$\overline{X} = 64$

$$S = \sqrt{\frac{2050}{3}} = \sqrt{683} = 26.1$$

Reject 29 if $Q \geq 1.53$ **

$$Q = \frac{35}{26.1} = 1.34$$

Cannot reject 29

$$64 - \frac{26.1\ (3.182)}{2} \leq \mu \leq 64 = \frac{26.1(3.182)}{2}$$

$$64 - 41.5 \leq \mu \leq 64 + 41.5$$

$$22 \leq \mu \leq 100$$

BOD Removal Using Alum

X	$X-\overline{X}$	$(X-\overline{X})^2$
73	26	676
59	12	144
50	3	9
28	-19	361
27	-20	400
237		1590
47.4		

$\overline{X} = 47$

$$S = \sqrt{\frac{1590}{4}} = \sqrt{398} = 19.95$$

$$47 - 19.95\frac{(2.776)}{\sqrt{5}} \leq \mu \leq 47 + 19.95\frac{(2.775)}{\sqrt{5}}$$

$$47 - 24.8 \leq \mu \leq 47 + 24.8$$

$$22 \leq \mu \leq 71$$

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods.

Removal of Suspended Solids Using Alum and Tretolite FR-50

X	$X-\bar{X}$	$(X-\bar{X})^2$
100.0	30.8	948.6
88.4	19.2	368.6
78.8	9.6	92.2
77.5	8.3	69.2
73.0	3.8	14.4
71.0	1.8	3.2
58.2	-11.0	121.0
*55.4	--	
54.1	-15.1	228.0
51.3	-17.9	320.4
*42.4		
39.6	-29.6	876.2
*12.4		
691.9		3041.8
69.2		

* Eliminated because of blood present or low pH (3.2).

$$S=\sqrt{\frac{3042}{10}} = \sqrt{304} = 17.4$$

Eliminate 39.6% and 100 % as outliers.

X	$X-\bar{X}$	$(X-\bar{X})^2$
88.4	19.4	376.4
78.8	9.8	96.0
77.5	8.5	72.2
73.0	4.0	16.0
71.0	2.0	4.0
58.2	-10.8	116.6
54.1	14.9	222.0
51.3	17.7	313.3
552.3		1216.5
69.0		

$\bar{X} = 69$

$$S = \sqrt{\frac{1216.5}{8}} = \sqrt{173.8} = 13.2$$

$$69.0 - \frac{13.2(2.365)}{\sqrt{8}} \leq \mu \leq 69.0 + \frac{13.2(2.365)}{\sqrt{8}}$$

$$69.0 - 11.0 \leq \mu \leq 69.0 + 11.0$$

$$58.0 \leq \mu \leq 80.0$$

Removal of Suspended Solids Using Alum and Dow 1188.1A

Chemical feed rate adjusted to give least turbidity.

X	$X-\bar{X}$	$(X-\bar{X})^2$
97.2	3.9	15.21
96.5	3.2	10.24
92.9	0.4	.16
92.3	1.0	1.00
87.6	5.7	32.49
466.5		59.10
93.3		

$\bar{X} = 93$

$$S = \sqrt{\frac{59.10}{4}} = \sqrt{14.77} = 3.84$$

$$93.3 - \frac{3.84(2.776)}{\sqrt{5}} \leq u \leq 93.3 + \frac{3.84(2.776)}{\sqrt{5}}$$

$$93.3 - 4.8 \leq \mu \leq 93.3 + 4.8$$

$$88.5 \leq \mu \leq 98.1$$

Removal of Suspended Solids Using Alum and Dow SA1188.1A

Chemical feed rate varied by pattern

4 mg/l SA 1188.1A + 75 mg/l and 100 mg/l alum

8 mg/l SA 1188.1A + 75 mg/l and 100 mg/l alum

X	$X-\bar{X}$	$(X-\bar{X})^2$
*77.4	9.5	90.25
71.6	3.7	13.69
65.1	-2.8	7.84
63.6	-4.3	18.49
61.8	6.1	37.21
339.5	Totals	167.48

67.9

$\bar{X}$ = 68

$$S = \sqrt{\frac{167.48}{4}} = \sqrt{41.87} = 6.47$$

$$67.9 - \frac{6.47(2.776)}{\sqrt{5}} \leq \mu \leq 67.9 + \frac{6.47(2.776)}{\sqrt{5}}$$

$$67.9 - 8.0 \leq \mu \leq 67.9 + 8.0$$

$$59.9 \leq \mu \leq 759$$

* Heavy blood load in the influent stream.

One experiment was performed in which all flow (350 GPM) was forced through one cell of the flotation tank. This in effect halved the retention time in the flotation tank. 75 mg/l alum and 50 mg/l Dow SA1188.1A were used as flocculation aids.

Input was 207 mg/l T.S.S.; output T.S.S. was 30 mg/l for a removal rate of 85.5%. The test was of 4 hours duration.

Removal of Suspended Solids

Using $FeCl_3$ only

$$S = \sqrt{\frac{0.50}{1}} = 0.707$$

X	$X-\overline{X}$	$(X-\overline{X})^2$
90.7	0.5	0.25
89.8	-0.5	0.25
180.5		0.50
90.2		

$$90.2 - \frac{(.71)(12.7)}{\sqrt{2}} \leq \mu \leq 90.2 + \frac{(.71)(12.7)}{\sqrt{2}}$$

$$90.2 \leq 6.4 \leq \mu \leq 90.2 + 6.4$$

$$83.8 \leq \mu \leq 96.6$$

$\overline{X} = 90$

Using $FeCl_3$ + Alum + Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
92.1	3.3	10.89
97.4	2.0	4.00
96.6	1.2	1.44

$$S = \sqrt{\frac{16.33}{3}} = \sqrt{5.44} = 2.33$$

$$95.4 - \frac{2.33(4.3)}{3} \leq \mu \leq 95.4 + \frac{2.33(4.3)}{3}$$

$\overline{X} = 95$

$$95.4 - 5.8 \leq \mu \leq 95.4 + 4.6$$

$$89.2 \leq \mu \leq 100$$

ONE WAY ANALYSIS OF VARIANCE

SUSPENDED SOLIDS REMOVAL DURING NON-RAIN EVENTS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\overline{X}$
No Rain						
No Chemicals	432	186624	26720	7	26661	62
Alum	258	66564	18690	4	16641	64
Alum + Tretolite	552	304704	39320	9	33856	69
Alum + Dow SA1188.1A	467	218089	43482	5	43618	93
Totals	1709		128212	25	120776	

$k = 4$
$k - 1 = 3$
$N = 25$
$N - k = 21$
$\alpha = 0.05$
$F = 3.07$

$T = 1709$

$C = \frac{T^2}{N} = \frac{2920681}{25} = 116827$

$SSB = \sum \frac{T_i^2}{n} - C$

$SSB = 120776 - 116827 = 3949$

$SST = \sum\sum X_i^2 - C$

$SST = 128212 - 116827 = 11385$

$SSE = SST - SSB = 11385 - 3949 = 7436$

$MSB = \frac{SSB}{k-1} = \frac{3949}{3} = 1316$

$MSE = \frac{7436}{21} = 354$

$F = \frac{MSB}{MSE} = 3.72$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	3	3949	1316
Error	21	7436	354
Total	24	11385	

DUNCAN'S MULTIPLE RANGE TEST

(MODIFIED VERSION)

Suspended solids removal using various combinations of chemicals

Non-Rain Events

No Chemicals
Alum

		$\overline{X}$
1.	Alum + Tretolite FR-50	69
2.	Alum + Dow SA1188.1A	93

$$S_{\bar{x}} = \sqrt{\frac{(MSE)2}{r_1+r_2}} = \sqrt{\frac{(354)2}{14}} = 50.6 = 7.11$$

r_1 & r_2 = **Sample sizes**

$\alpha = 0.5; \; N_2 = 21$

P = 2

SSR	2.94
LSR = (SSR)$S_{\bar{x}}$	20.9

	1	2
Ranked Means	69	93

Means	Diff	P	LSR
2-1	21	2	20.9

Decision: There is a significant difference between the rates of suspended solids removal for alum and Dow SA1188.1A. Inspection shows that the difference between the suspended solids removal rate for alum and Dow SA1188.1A and the other treatments would also be significant.

TABLE D-8

One way analysis of variance for suspended solids removal rate as indicated below. The chemical treatments to be analyzed include: (1) No chemicals; (2) Alum only; (3) Alum plus Tretolite FR-50; and (4) Alum plus Dow SA1188.1A.

Null Hypothesis

H_o: There is no significant difference between the total suspended solids removal rates for the chemical operations listed above.

Alternate Hypothesis

H_a: There is a significant difference between the total suspended solids removal rates listed for the chemical operations listed above.

$\alpha = 0.05$

F_α - 3.07

Criteria: Reject H_o if $F > F$; reserve judgement if $F \leq F_\alpha$.

Result: $F = 3.71$

Decision: F is greater than F_α , therefore reject H_o. There is a significant difference between these mean total suspended solids removal rates.

The application of the modified version of Duncan's Multiple Range Test indicates that a difference exists between the chemical treatment using alum plus Dow SA1188.1A and the other chemical treatments.

Total Solids Removal

Using No Chemical Treatment

X	X-$\overline{X}$	$(X-\overline{X})^2$
40	21	441
26	7	49
24	5	25
17	- 2	4
10	- 9	81
10	- 9	81
7	-12	144
134		825
19.1		

$\overline{X} = 19$

$$S = \sqrt{\frac{825}{6}} = \sqrt{137.5} = 11.8$$

$$19.1 - \frac{11.8(2.365)}{\sqrt{7}} \leq \mu \leq 19.1 + \frac{11.8(2.365)}{\sqrt{7}}$$

$$19.1 - 10.5 \leq \mu \leq 19.1 + 10.5$$

$$9 \leq \mu \leq 30\%$$

Total Solids Removal Using Alum

X	$X-\bar{X}$	$(X-\bar{X})^2$
43	9	81
41	7	49
31	-3	9
19	-15	225
134		364

335

$\bar{X} = 34$

$$S = \sqrt{\frac{364}{3}} = \sqrt{121.3} = 11$$

$$33.5 - \frac{(11)(3.182)}{2} \leq \mu \leq \frac{11(3.182)}{2} + 33.5$$

$$33.5 - 17.5 \leq \mu \leq 33.5 + 17.5$$

$$16 \leq \mu \leq 51$$

Total Solids Removal Using Alum and Tretolite FR-50

X	$(X-\bar{X})$	$(X-\bar{X})^2$
34	17	289
31	14	196
29	12	144
26	9	81
13	-4	16
13	-4	16
4	-13	169
2	-15	225
2	-15	225
154		1361

17.1

$\bar{X} = 17$

$$S = \sqrt{\frac{1361}{8}} = \sqrt{170.1} = 13.0$$

$$17.1 - \frac{13(2.306)}{3} \leq \mu \leq 17.1 + \frac{13(2.306)}{3}$$

$$17.1 - 9.9 \leq \mu \leq 17.1 + 9.9$$

$$7.2 \leq \mu \leq 27$$

ONE WAY ANALYSIS OF VARIANCE

Total Solids Removal Using Various Chemical Treatments

	T_i	T_i^2	T_i^2	n	T_i^2/n	$\overline{X}$
No Chemicals	134	17956	3390	7	2565	19
Alum	134	17956	4862	4	4489	34
Alum + Tretolite FR-50	171	29241	3996	9	3249	17
Alum + Dow SA1188.1A	185	34225	6707	6	5704	31
Totals	624		18955	26	16007	

$k = 4$
$k - 1 = 3$
$N = 26$
$N - k = 22$
$\alpha = 0.05$
$F = 3.05$

$T = 624$

$$C = \frac{T^2}{N} = \frac{(624)^2}{26} = \frac{389376}{26} = 14976$$

$$SSB = \sum \frac{T_i^2}{N} - C = 16007 - 14976 = 1031$$

$$SST = \sum\sum X_i^2 - C = 18955 - 14976 = 3979$$

$$SSE = SST - SSE = 3979 - 1031 = 2948$$

$$MSB = \frac{SSB}{k-1} = \frac{1031}{3} = 344$$

$$MSE = \frac{SSE}{N-k} = \frac{2948}{22} = 134$$

$$F = \frac{MSB}{MSE} = \frac{344}{134} = 2.57$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	3	1031	344
Error	22	2948	134
Total	25	3979	

TABLE D-9

One way analysis of variance of removal of total solids with the various chemical treatments listed below. The chemical treatments to be analyzed include: (1) no chemicals; (2) alum only; (3) alum plus Tretolite FR-50; (4) alum plus Dow SA1188.1A.

Null Hypothesis

H_o: There is no significant difference between the rates of removal of total solids using the various chemical treatments listed above.

Alternate Hypothesis

H_a: There is a significant difference between the rates of removal of total solids using the various chemical treatments listed above.

$\alpha = 0.05$

$\alpha = 3.05$

Criteria: Reject H_o if $F \leq F_\alpha$; reserve judgment if $F < F_\alpha$.

Result: $F = 2.57$

Decision: F is less than F_α , therefore, reserve judgment. There is no significant difference in the total solids removal rates using the chemical treatments listed above.

BOD Removal Using No Chemical Treatment

X	$X-\overline{X}$	$(X-\overline{X})^2$
59	27	729
36	4	16
27	-5	25
27	-5	25
21	-11	121
19	-13	169
189		1085
31.5		

$$S = \sqrt{\frac{1085}{5}} = \sqrt{217}$$

$$S = 14.7$$

If $Q \geq 1.73$, Reject 59**

$$Q = \frac{27}{14.7} = 183,$$ Reject 59

X	$X-\overline{X}$	$(X-\overline{X})^2$
36	10	100
27	1	1
27	1	1
21	-5	25
19	-7	49
130		176
26		

$$S = \sqrt{\frac{176}{4}} = \sqrt{44} = 6.633$$

$$\overline{X} = 26$$

$$26 - \frac{6.63(2.776)}{\sqrt{5}} \leq u \leq 26 + \frac{6.63(2.776)}{\sqrt{5}}$$

$$26 - 8.2 \leq \mu \leq 26 + 8.2$$

$$18 \leq \mu \leq 34$$

** Application of Chauvenet's Criteria; critical values found in Table A-6, Basic Statistical Methods.

BOD Removal Using Alum and Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
89	36	1296
77	24	576
71	18	324
70	17	289
58	5	25
56	3	9
53	0	0
51	-2	4
36	-17	289
31	-22	484
28	-25	625
18	-35	1225
638		5146
53.2		

$\overline{X} = 53$

$$S = \sqrt{\frac{5146}{11}} = \sqrt{467.8} = 21.6$$

$$53 - \frac{21.6(2.201)}{\sqrt{12}} \leq \mu \leq 53 + \frac{21.6(2.201)}{\sqrt{12}}$$

$$53 - 13.7 \leq \mu \leq 53 + 13.7$$

$$39.3 \leq \mu \leq 65.7$$

BOD Removal Using
Alum and Dow SA1188.1A

X	$X-\overline{X}$	$(X-\overline{X})^2$
76	13	169
74	11	121
71	8	64
49	-14	196
46	-17	289
316		837
63.2		

$\overline{X} = 63.2$

$$S = \sqrt{\frac{837}{4}} = \sqrt{209} = 14.46$$

$$63 - \frac{14.5(2.776)}{\sqrt{5}} \le \mu \le 63 + \frac{14.5(2776)}{\sqrt{5}}$$

$$63 - 18.0 \le \mu \le 63 + 18.0$$

$$45 \le \mu \le 81$$

Suspended Solids Removal Using DOW-SA1188.1A

X	$X-\overline{X}$	$(X-\overline{X})^2$
54	23	529
37	6	36
29	-2	-4
28	-3	9
26	-5	25
11	20	400
185		
30.8		

$$S = \sqrt{\frac{1003}{5}} = \sqrt{201} = 14.2$$

$$30.8 - \frac{14.2(2.571)}{\sqrt{6}} \le \mu \le 30.8 + \frac{14.2(2.571)}{\sqrt{6}}$$

$$30.8 - 14.9 \le \mu \le 30.8 + 14.9$$

$$16 \le \mu \le 46$$

BOD Removal

Using $FeCl_3$ Only

X	$X-\overline{X}$	$(X-\overline{X})^2$
22	+20	400
62	-20	400
84		800
42		

$$S = \sqrt{800} = 28.28$$

$$5 \leq \mu \leq 80 \; *$$

$\overline{X} = 42$

Using $FeCl_3$ + Alum + Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
88		6.25
83	-2.5	6.25
171		12.50
85.5		

$$S = \sqrt{\frac{12.50}{1}} = 3.54$$

$\overline{X} = 86$

$$86 - \frac{3.54(12.7)}{\sqrt{2}} \leq \mu \leq 86 + \frac{3.54(12.7)}{\sqrt{2}}$$

$$85.5 - 32 \leq \mu \leq 85.5 + 32$$

$$54 \leq \mu \leq 100$$

---

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

ONE WAY ANALYSIS OF VARIANCE

BOD REDUCTION USING VARIOUS CHEMICAL COMBINATIONS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\bar{X}$
No Chemicals	130	16900	3556	5	3380	26
Alum	237	15169	12823	5	11234	47
Alum + Tretolite	638	407044	39066	12	33920	53
Alum + Dow SA1188.1A	316	99856	20810	5	19971	63
TOTALS	1321		76255	27	68505	

$k = 4$

$k - 1 = 3$

$N = 27$

$N - k = 23$

$\alpha = 0.05$

$F = 3.03$

$$T = 1321$$

$$C = \frac{T^2}{N} = \frac{1745041}{27} = 64631$$

$$SSB = \sum \frac{T_i^2}{n} - C = 68505 - 64631 = 1874$$

$$SST = \sum \sum X_i^2 - C = 76255 - 64631 = 11624$$

$$SSE = SST - SSB = 9750$$

$$MSB = \frac{SSB}{k-1} = \frac{1874}{3} = 625$$

$$MSE = \frac{SSE}{N-k} = \frac{9750}{23} = 424$$

$$F = \frac{MSB}{MSE} = \frac{625}{424} = 1.74$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	3	1874	624
Error	23	9750	
Total	26	11624	

TABLE D-10

One way analysis of variances of BOD reduction using all separatory equipment with various chemical treatments as indicated below. The chemical include: (1) no chemicals, (2) alum only, (3) alum plus Tretolite FR-50, and (4) alum plus Dow SA1188.1A.

Null Hypothesis

H_o: There is no significant difference between the rates of BOD reduction for the chemical treatments listed above.

Alternate Hypothesis

H_a: There is a significant difference between the rates of BOD reduction for the chemical treatments listed above.

$\alpha = 0.05$

$F_\alpha = 3.03$

Criteria: Reject H_o if $F > F$; reserve judgement if $F \leq F_\alpha$.

Result: $F = 1.47$

Decision: F is less than F_α , therefore the null hypothesis cannot be rejected.

The one-way analysis of variance indicates that there is apparently no significant difference between the rates of BOD reduction for the chemical treatments listed above.

Total Phosphate Removal

Using No Chemical Treatment

X	$X-\overline{X}$	$(X-\overline{X})^2$
67	38	1444
52	23	529
21	- 8	64
20	- 9	81
8	-21	441
6	-23	529
174		3088
29		

$\overline{X} = 29$

$$S = \sqrt{\frac{3088}{5}} = \sqrt{617.6} = 24.84$$

$$29 - \frac{2.571(24.84)}{2.236} \leq \mu \leq 29 + \frac{(2.571)(24.84)}{2.236}$$

$$29 - 28.6 \leq \mu \leq 29 + 28.6$$

$$0 \leq \mu \leq 58$$

Total Nitrogen Removal

Using No Chemical Treatment

X	$X-\overline{X}$	$(X-\overline{X})^2$
16	3.4	11.56
14	1.4	1.96
12	- .6	.36
11	-1.6	2.56
10	-2.6	6.76
63		23.20
12.6		

$\overline{X} = 13$

$$S = \sqrt{\frac{23.20}{4}} = \sqrt{5.8} = 2.408$$

$$12.6 - \frac{2.41(2.776)}{\sqrt{5}} \leq \mu \leq 12.6 + \frac{2.41(2.776)}{\sqrt{5}}$$

$$12.6 - 3.0 \leq \mu \leq 12.6 + 3.0$$

$$9.6 \leq \mu \leq 15.6$$

Total Phosphate Removal Using Alum

X	$X-\overline{X}$	$(x-\overline{x})^2$
78	25	625
69	14	196
48	-5	25
39	-14	196
31	-22	484
265		1526
53		

$\overline{X} = 53$

$$S = \sqrt{\frac{1526}{4}} = \sqrt{381.5} = 19.53$$

$$53 - \frac{(19.53)(2.776)}{2.236} \leq \mu \leq 53 + \frac{(19.53)(2.776)}{2.236}$$

$$53 - 24.2 \leq \mu \leq 53 + 24.2$$

$$29 \leq \mu \leq 77$$

Total Nitrogen Removal Using Alum

X	$X-\overline{X}$	$(X-\overline{X})^2$
21		
17		
7	2.25	5.0625
4	.75	.5625
4	.75	.5625
4	.75	.5625
19		6.75
4.75		

$\overline{X} = 5$

$$S = \sqrt{\frac{6.75}{3}} = \sqrt{2.25} = 1.5$$

$$4.75 - \frac{(1.5)(3.182)}{2} \leq \mu \leq 4.75 + \frac{(1.5)(3.182)}{2}$$

$$4.75 - 2.75 \leq \mu \leq 4.75 + 2.75$$

$$2.0 \leq \mu \leq 7.5$$

Total Phosphate Removal Using Alum and Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
75	32	1024
64	21	441
60	17	289
42	-1	1
38	-5	25
37	-6	36
31	-12	144
25	-18	324
14	-31	961
386		3245 +
42.9		

$\overline{X} = 43$

$$S = \sqrt{\frac{3245}{8}} = \sqrt{405.6} = 20.14$$

$$43 - \frac{(20.14)(2.306)}{3} \leq \mu \leq 43 + \frac{(20.14)(2.306)}{3}$$

$$43 - 15.5 \leq \mu \leq 43 + 15.5$$

$$27 \leq \mu \leq 59$$

Total Nitrogen Removal Using Alum and Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
30	Eliminated as Outliers	
24		
8	3	9
8	3	9
7	2	4
7	2	4
2	-3	9
2	-3	9
1	-4	10
35		60
5		

$\overline{X} = 5$

$$S = \sqrt{\frac{60}{6}} = \sqrt{10} = 3.162$$

$$5 - \frac{(3.16)(2.447)}{\sqrt{7}} \leq u \leq 5 + \frac{(3.16)(2.447)}{\sqrt{7}}$$

$$5 - 2.9 \leq \mu \leq 5 + 2.9$$

$$2 \leq \mu \leq 8$$

Total Phosphate Removal Using Alum plus Dow SA1188.1A

X	$X-\overline{X}$	$(X-\overline{X})^2$
57	23	529
44	10	100
37	3	9
21	13	169
12	22	484
171		1291
34.2		

$\overline{X} = 34$

$$S = \sqrt{\frac{1291}{4}} = \sqrt{322.7} = 17.96$$

$$34.2 - \frac{17.96(2.776)}{2.336} \leq \mu \leq 34.2 + \frac{(17.96)(2.776)}{2.336}$$

$$34.2 - 22.3 \leq \mu \leq 34.2 + 22.3$$

$$12 \leq \mu \leq 56$$

Total Nitrogen Removal Using Alum plus Dow SA1188.1A

X	$X-\overline{X}$	$(X-\overline{X})^2$
17	10	100
16	9	81
0	7	49
0	7	49
0	7	49
33		328
6.6		

$\overline{X} = 7$

$$S = \sqrt{\frac{328}{4}} = \sqrt{82} = 9.06$$

$$6.6 - \frac{(9.1)(2.776)}{\sqrt{5}} \leq \mu \leq 6.6 + \frac{(9.1)(2.776)}{\sqrt{5}}$$

$$6.6 - 11.3 \leq \mu \leq 6.6 + 11.3$$

$$0 \leq \mu \leq 17.9$$

Total Phosphate Removal

Using $FeCl_3$ Only

X
73
73
146
73

$\bar{X} = 73$

$S = 0$

$30 \le \mu \le 100$ *

Using $FeCl_3$ + Alum + Tretolite FR-50

X	$X-\bar{X}$	$(X-\bar{X})^2$
90	9.5	90.25
71	9.5	90.25
161		180.5
80.5		

$S = \sqrt{180.5} = 13.4$

$\bar{X} = 80$

$35\% \le \mu \le 100\%$ *

Total Nitrogen Removal

Using $FeCl_3$ Only

X	$X-\bar{X}$	$(X-\bar{X})^2$
9	3	9
3	-3	9
12		18
6		

$S = \sqrt{18} = 4.242$

$FeCl_3$

$0\% \le \mu \le 50\%$

Using $FeCl_3$ + Alum + Tretolite FR-50

X	$X-\bar{X}$	$(X-\bar{X})^2$
5	2.5	6.25
0	2.5	6.25
5		12.5
2.5		

$S = \sqrt{12.5} = 3.46$

$\bar{X} = 2$

$0\% \le \mu \le 45\%$ *

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

ONE WAY ANALYSIS OF VARIANCE

TOTAL PHOSPHATE REMOVAL USING CHEMICAL TREATMENT

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\overline{X}$
No Chemicals	174	30276	8134	6	5046	29
Alum	265	70225	15631	5	14045	53
Alum + Tretolite FR-50	386	148996	18680	9	16555	43
Alum + Dow SA1188.1A	171	29241	7139	5	5848	34
Totals	996		49584	25	41494	

$k = 4$
$k - 1 = 3$
$N = 25$
$N - k = 21$
$\alpha = 0.05$
$F_\alpha = 3.07$

$$C = \frac{T^2}{N} = \frac{996}{25} = \frac{992016}{25} = 39681$$

$$SSB = \sum\frac{T_i^2}{n} - C = 41494 - 39681 = 1813$$

$$SST = \sum\sum X_i^2 - C = 49584 - 39681 = 9903$$

$$SSE = SST - SSB = 9903 - 1813 = 8090$$

$$MSB = \frac{SSB}{k-1} = \frac{1813}{3} = 604$$

$$MSE = \frac{SSE}{N-k} = \frac{8090}{21} = 385$$

$$F = \frac{MSB}{MSE} = \frac{604}{385} = 1.57$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	3	1813	604
Error	21	8090	
Total	24		

TABLE D-11

One way analysis of variance of removal of total phosphate with the chemical treatments listed below. The chemical treatments to be analyzed include (1) no chemicals; (2) alum only; (3) alum plus Tretolite FR-50; and (4) alum plus Dow SA1188.1A.

H_o: There is no significant difference between the phosphorous removal rates using the various chemical treatments listed above.

Alternate Hypothesis

H_a: There is a significant difference between the phosphorous removal rates using the various chemical treatments listed above.

$\alpha = 0.05$

$F_\alpha = 3.07$

Criteria: Reject H_o if $F > F_\alpha$, reserve judgement if $F \leq F_\alpha$.

Result: $F = 1.57$

Decision: F is less than F_α, therefore reserve judgement. There is no significant difference between the total phosphate removal rates with various chemical treatments listed above.

ONE WAY ANALYSIS OF VARIANCE

TOTAL NITROGEN REMOVAL USING CHEMICAL TREATMENTS

	T_i	T_i^2	X_i^2	n	T_i^2/n	$\overline{X}$
No Chemicals	64	4096	818	6	683	11
Alum	19	361	97	4	90	5
Alum + Tretolite FR-50	35	1225	235	7	175	5
Alum + Dow SA1188.1A	33	1089	545	5	218	7
Totals	151		1695	22	1166	

$k = 4$

$k-1 = 3$

$N = 22$

$N-k = 18$

$\alpha = 0.05$

$F_\alpha = 3.16$

$T = 151$

$$C = \frac{T^2}{N} = \frac{22801}{22} = 1036$$

$$SSB = \sum \frac{T_i^2}{n} - C = 1166 - 1036 = 130$$

$$SST = \sum\sum X_i^2 - C = 1695 - 1036 = 659$$

$$SSE = 529$$

$$MSB = \frac{SSB}{k-1} = \frac{130}{3} = 43.3$$

$$MSE = \frac{SSE}{N-k} = \frac{529}{18} = 29.4$$

$$F = \frac{MSB}{MSE} = \frac{43.3}{29.4} = 1.47$$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between Samples	3	130	43.3
Error	18	529	29.4
Total	21	659	

TABLE D-12

One way analysis of variance of the removal of total nitrogen with the various chemical treatments listed below. Chemical treatments to be analyzed include: (1) no chemicals, (2) alum only, (3) alum plus Tretolite FR-50, and (4) alum plus Dow SA1188.1A.

Null Hypothesis

H_o: There is no significant difference between the mean nitrogen removal rates using the chemical treatments listed above.

Alternate Hypothesis

H_a: There is a significant difference between the mean nitrogen removal rates using the chemical treatments listed above.

$\alpha = 0.05$

$F_\alpha = 3.16$

Criteria: Reject H_o if $F > F_\alpha$; reserve judgement if $F \leq F_\alpha$.

Result: $F = 1.47$

Decision: F is less than F_α , therefore reserve judgement. There is no significant difference between the total nitrogen removal rates using the various chemical treatments listed above.

Computations of mean rates of suspended solids, BOD, total solids, total phosphates, and total nitrogen removal using all separatory equipment, alum and Dow SA1188.1A.

Waste Flow Rate = 350 GPM

Δp = 50 psi

Air Feed Rate = 30 cfm

X = % Removal

95 percent confidence interval was calculated using values found in the Manual of Experimental Statistics (38).

$$S= \frac{\sqrt{(X-X)^2}}{N-1}$$

Where
X = Removal Rates
$\bar{X}$ = Mean Removal Rate
N = Number of Observations
μ = Mean Population Removal Rate

$$X - \frac{tS}{N} \le \mu \le \frac{tS}{N} + X$$

Removal of Suspended Solids Using Screen, Three Secondary Cyclones and Flotation Cell + Alum and Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
90	1	1
88	- 1	1
178		2
89		

$\overline{X} = 89$

$$S = \sqrt{\frac{2}{1}} = 1.414$$

$$89 - \frac{(1.414)(12.7)}{\sqrt{2}} \leq \mu \leq 89 + \frac{(1.414)(12.7)}{\sqrt{2}}$$

$$89 - 12.7 \leq \mu \leq 89 + 12.7$$

$$\therefore \quad 75\% \leq \mu \leq 100\%$$

Removal of BOD Using Screen, Three Secondary Cyclones and Flotation Cell + Alum and Tretolite FR-50

X	$X-\overline{X}$	$(X-\overline{X})^2$
80	11.5	132.25
57	11.5	132.25
137		264.5
68.5		

$\overline{X} = 68$

$$S = \sqrt{264.5} = 16.2$$

$$25 \leq \mu \leq 100 \; *$$

---

* 95% confidence interval obtained from Table V, Manual of Experimental Statistics.

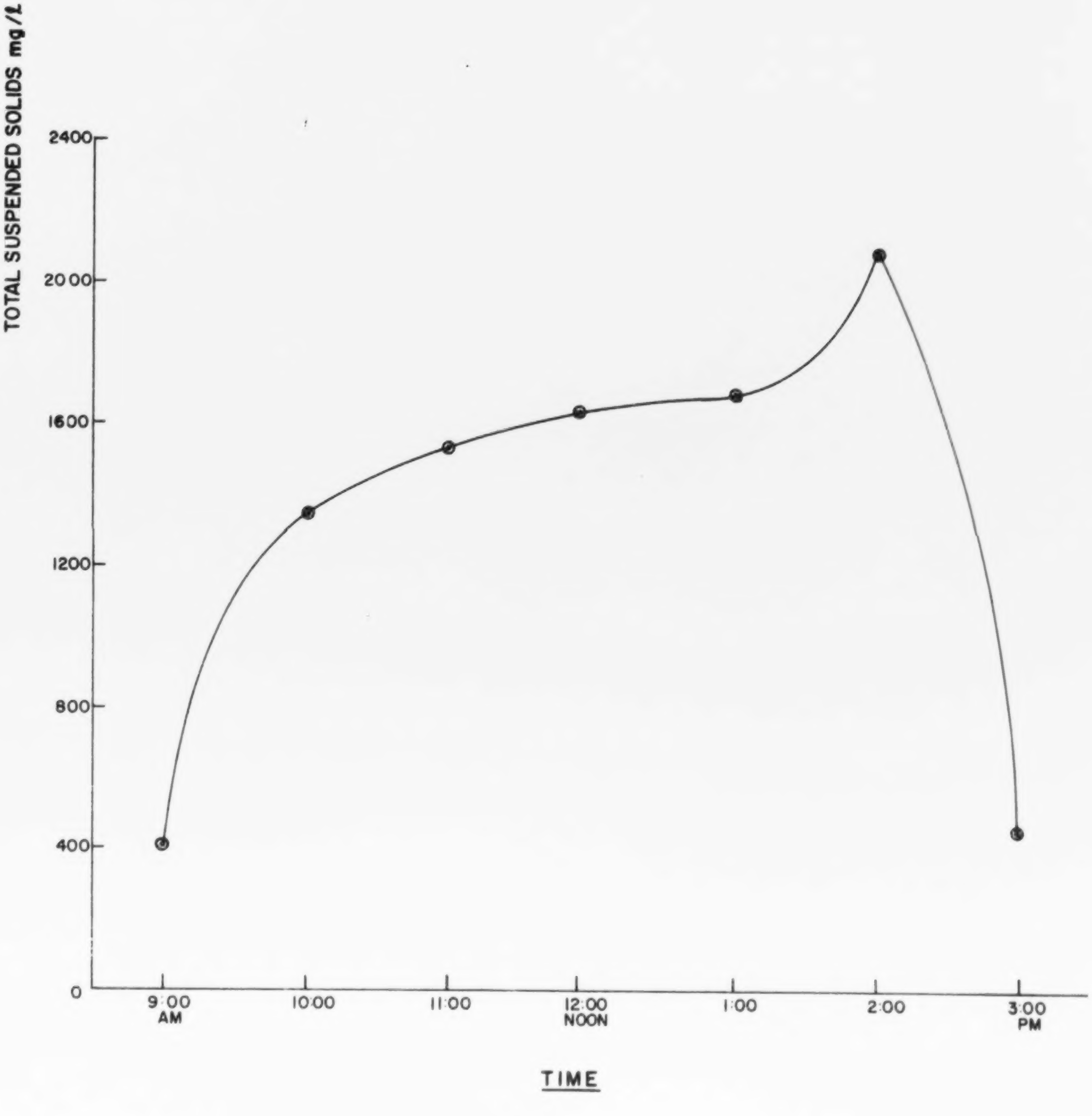
APPENDIX E

TYPICAL DATA OBTAINED DURING PLANT SHAKEDOWN IN 1967

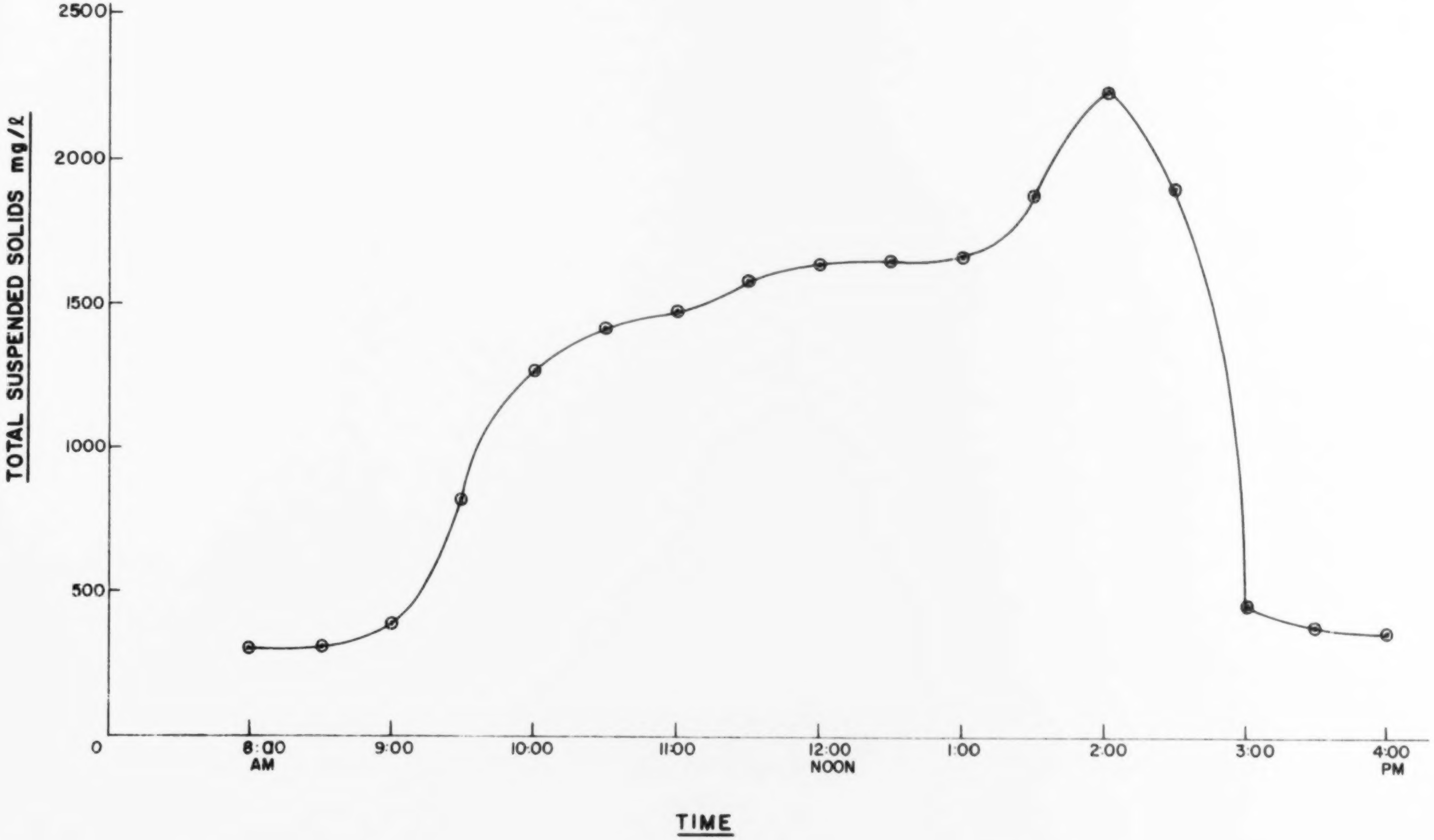
Data accumulated during the commissioning and equipment shakedown exercises in late 1967 indicated that the waste influent contained a widely varying load of industrial solids: dissolved and suspended.

Graphs of some of the data obtained illustrate the hourly and daily variations. The relatively low suspended solids content on November 18th and 19th clearly suggests a weekend with little industrial activity. These graphs are included on the following pages.

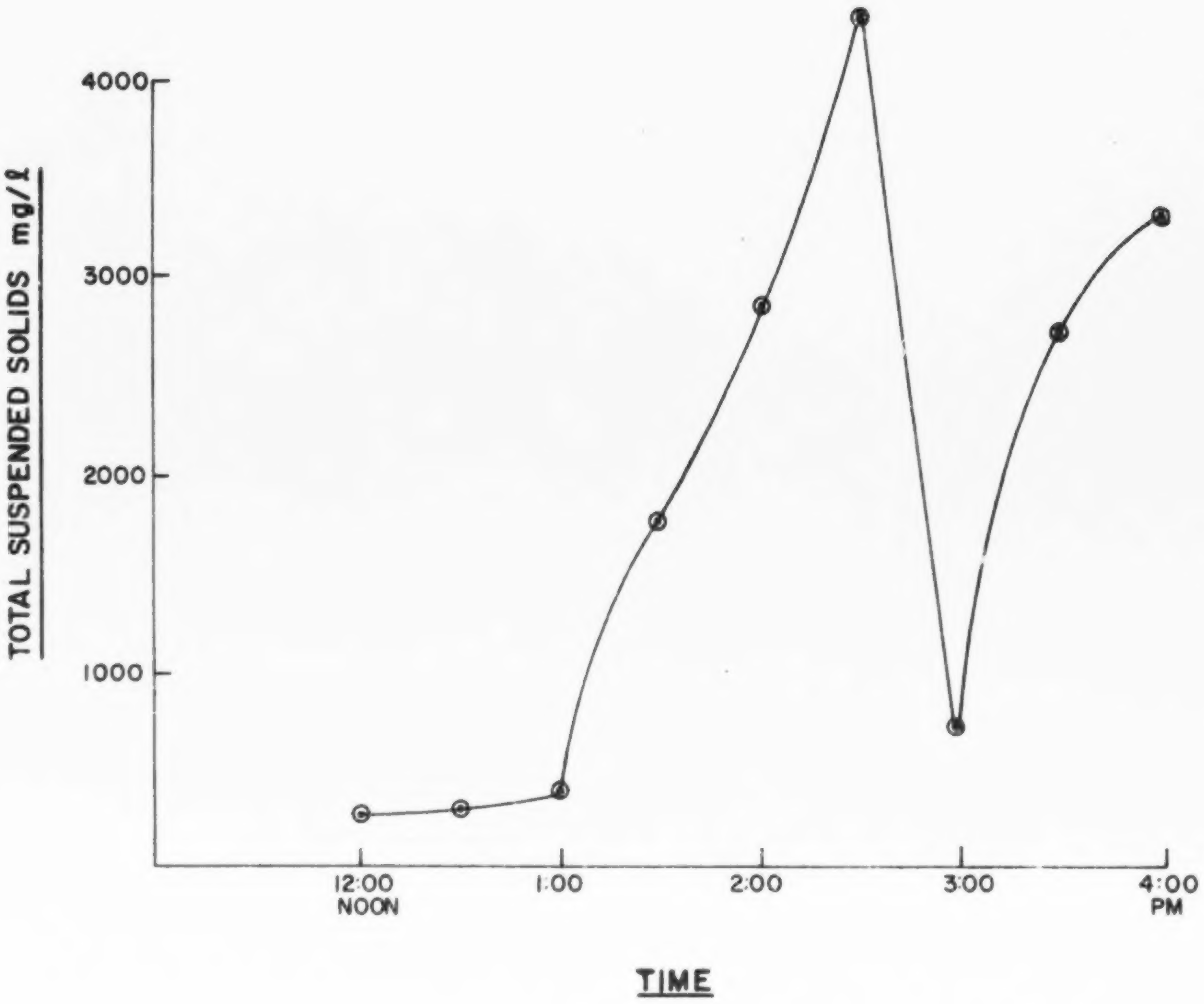
VARIATION OF TOTAL SOLIDS WITH TIME WEDNESDAY DEC. 13, 1967



VARIATION OF SUSPENDED SOLIDS WITH
TIME WEDNESDAY DECEMBER 13, 1967



VARIATION OF SUSPENDED SOLIDS WITH TIME WEDNESDAY DEC. 6, 1967



TOTAL SOLIDS mg/ℓ AS A FUNCTION OF TIME
WED. NOV.15 THROUGH SUNDAY NOV. 19,1967